Outline of Music Semantics*

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[This is a summary of 'Prolegomena to Music Semantics' [http://ling.auf.net/lingbuzz/002925], which discusses several issues that are omitted here – notably: the role of emotions in music semantics, music pragmatics, and the radical differences between music semantics and linguistic semantics.]

Note: Whenever possible, links to audiovisual examples have been included in the text.

Abstract. We provide the outline of a semantics for music. We take music cognition to be continuous with normal auditory cognition, and thus to deliver inferences about 'virtual sources' of the music (as in Bregman's Auditory Scene Analysis). As a result, sound parameters that trigger inferences about sound sources in normal auditory cognition produce related ones in music – as is the case when decreasing loudness signals the end of a piece because the source is gradually losing energy, or moving away. But what is special about music is that it also triggers inferences on the basis of the movement of virtual sources in tonal pitch space, which has points of stability (e.g. a tonic chord), points of instability (e.g. dissonant chords), and relations of attractions among them (e.g. a dissonant chord tends to be resolved). In this way, gradual movement towards a point of tonal stability, as in a cadence, may also serve to signal the end of a piece, but on the basis of tonal information. The challenge is thus to develop a framework that aggregates inferences from normal auditory cognition and tonal inferences. We sketch such a framework in a highly simplified case, by arguing that a source undergoing a musical movement *m* is true of an object undergoing a series of events *e* just in case there is a certain structure-preserving map between *m* and *e*. Thus we require that inferences triggered by loudness on the relative levels of energy or proximity among events should be preserved, and similarly for tonal inferences pertaining to the relative stability of events. This yields a 'bare bones' version of a music semantics, as well as a definition of 'musical truth'. We then argue that this framework can help re-visit some aspects of musical syntax. Specifically, we take (Lerdahl and Jackendoff's) *grouping structure* to reflect the mereology ('partology') of events that are abstractly represented in the music – hence the importance of Gestalt principles of perception in defining musical groups. Finally, we argue that this 'refentialist' approach to music semantics still has the potential to provide an account of diverse emotional effects in music.

1 Introduction

1.1 Goals

Can there be a music semantics, construed as *a set of principles that determine the informational content of a musical piece about a music-external reality*? Despite much discussion of the 'meaning of music' (see Antovic 2009 for an historical perspective), this question remains opaque. By contrast, the formal study of musical syntax has been the subject of numerous investigations, both theoretical and experimental (e.g. Lerdahl and Jackendoff 1983, Lerdahl 2001, Pesetsky and Katz 2009, Rohrmeier 2011, Granroth-Wilding and Steedman 2014, Patel 2003). Can formal and empirical progress be made on the semantic front as well?

In this paper, we sketch a positive (and programmatic) answer. Our guiding intuition is that *the meaning of a musical piece is given by the inferences that one can draw about its 'virtual sources'*, which in salient cases can be identified with the 'voices' of classical music theory. Our analysis is in two steps.

• First, we take properties of normal (non-musical) auditory cognition to make it possible to identify one or several 'virtual' sources of the music, and to license some inferences about them depending on some of their non-tonal properties (rhythm, loudness, patterns of repetition, etc). Thus *music semantics starts out as sound semantics*. Importantly, these sources are fictional, and need not correspond to actual sources: a single pianist may play several voices; and an orchestra may at some point play a single voice. Just as importantly, the inferences triggered are sufficiently abstract that the sources need not be viewed as producing sound (for instance, a low-pitched sound will under some circumstances trigger the inference that the virtual source is large, but not necessarily that it is producing sound).

• Second, we take further inferences about these sources to be drawn from their behavior within tonal pitch space. This space has properties that are very different from ordinary physical space, with different sub-spaces (major, minor, with different keys within each category), and locations (chords) that are subject to various degrees of stability and attraction. Inferences may be drawn on a (virtual) source depending on its behavior in this non-standard space.

To see an example of an inference from *normal auditory cognition*, consider loudness. One common way to signal the end of a piece is to gradually decrease the loudness. While this device may be taken to be conventional, it is plausible that it is derived from normal auditory cognition: a source that produces softer and softer sound may be losing energy, or moving away (we will see below that both types of inference can be triggered). In the system we develop, these inferences are indeed licensed, but in an abstract fashion, without entailing that the sources are producing sound. Turning to *tonal inferences*, it is also standard to mark the end of a piece by a sequence of chords that gradually reach maximal repose, ending on a tonic. Plausibly, an inference is drawn to the effect that a virtual source in a tonic position is in the most stable tonal position, hence not 'attracted' to other parts of tonal pitch space. In quite a few cases, these two types of inference conspire to mark the end of a piece. But as we will argue, numerous other semantic effects can be produced as well.

The challenge is thus to develop a framework that aggregates inferences from normal auditory cognition and tonal inferences. We sketch such a framework in a highly simplified case, by arguing that a source undergoing a musical movement *m* is true of an object undergoing a series of events *e* just in case there is a certain structure-preserving map between *m* and *e*. Thus we require that inferences triggered by loudness on the relative levels of energy or proximity among events should be preserved, and similarly for tonal inferences pertaining to the relative stability of events. This yields a 'bare bones' version of a music semantics, as well as a definition of 'musical truth'. It is obtained from entirely different means from truth in language: musical inferences are drawn by treating music as a kind of 'auditory trace' of some abstract sources, and not by a compositional procedure, as in human language.

We will then argue that this framework can help re-visit some aspects of musical syntax, along the lines of Lerdahl and Jackendoff 1983. Specifically, we will take their *grouping structure* to reflect the mereology ('partology') of events that are abstractly represented in the music – hence the importance of Gestalt principles of perception (rather than of a generative syntax) in defining musical groups. In other words, we take musical grouping to originate in an attempt to reconstruct the structure of events undergone by the virtual sources. In many cases, mereological relations yield a tree-like structure for groups, but as was already discussed in Lerdahl and Jackendoff 1983, there are some exceptions; we will argue that they follow from the mereological interpretation. We will further speculate that the asymmetric, 'headed' nature of musical groups (corresponding to Lerdahl and Jackendoff's 'time-span reductions') might reflect a more general tendency to analyze sub-events as

being more or less important for events they are part of. Finally, we will argue that our 'refentialist' approach to music semantics still has the potential to provide an account of diverse emotional effects triggered by music, in particular by way of inferences drawn on the emotions of animate sources.

1.2 Theoretical situation

To situate our enterprise, our framework seeks to integrate two intuitions that were developed in earlier analyses.

First, in KBregman's application of Auditory Scene Analysis to music, the listener analyzes the music as a kind of 'chimeric sound' which 'does not belong to any single environmental object' (Bregman 1994 chapter 5). As Bregman puts it, 'in order to create a virtual source, music manipulates the factors that control the formation of sequential and simultaneous streams'. Importantly, 'the virtual source in music plays the same perceptual role as our perception of a real source does in natural environments', which allows the listener to draw inferences about the virtual sources of the music. In Bregman's terms, 'transformations in loudness, timbre, and other acoustic properties may allow the listener to conclude that the maker of a sound is drawing nearer, becoming weaker or more aggressive, or changing in other ways'.

The second antecedent idea is that the semantic content of a musical piece is a kind of 'journey through tonal pitch space'. Lerdahl 2001 thus analyzes 'musical narrativity' in connection with a linguistic theory (Jackendoff 1982) in which 'verbs and prepositions specify places in relation to starting, intermediate, and terminating objects'. For him, music is equally 'implicated in space and motion': 'pitches and chords have locations in pitch space. They can remain stationary, move to other pitches or chords that are closer or far, or take a path above, below, through, or around other musical objects'. More recently, Granroth-Wilding and Steedman 2014 provide an explicit semantics for jazz sequences in terms of motion in tonal pitch space.

It is essential for us that that these two ideas should be combined within a single framework. An analysis based on Auditory Scene Analysis alone might go far in identifying the virtual sources and explaining some inferences they trigger on the basis of normal auditory cognition, but it would fail to account for the further inferences that one draws by observing the movement of the voices in tonal pitch space – for instance the fact that the end of piece is typically signaled by a movement towards greater tonal stability. Conversely, an analysis based solely on motion through tonal pitch space would miss many of the inferences about the sources that are drawn on the basis of normal auditory cognition (as in the case of decreasing volume), and more generally it would miss the fact that the sources can be construed as real world objects – an essential condition to obtain a *bona fide* semantics.

Besides these two antecedents, our analysis builds on numerous insights into music semantics that have been developed in the literature; we hope that the framework we sketch will make it possible to synthesize several in an organized fashion. One influential line of inquiry takes various semantic inferences to be based on the attribution of animancy and intentions to some musical elements such as pitches, chords, and motives (Lerdahl 2001, Maus 1988, Monahan 2013). A second but related line takes important semantic inferences to be triggered by sound properties found in animal signals and/or in human speech (Cook 2007, Cross and Woodruff 2008, Blumstein et al. 2012, Bowling et al. 2010, Huron 2015, Ilie and Thompson 2006, and Juslin and Laukka 2003). Both directions are compatible with Bregman's general enterprise, and our source-based semantics makes important use of these insights, but in the general case it does not require that the virtual sources should be animate. A third line of investigation takes music to trigger inferences about movement (Clarke 2001, Eitan and Granot 2006, Larson 2012, Saslaw 1996) – which is compatible with the analysis of musical meaning as a 'journey through tonal pitch space'. Our source-based semantics allows the virtual sources to move in space, but it allows for many other types of events as well. Relatedly, a fourth line of investigation takes certain properties of music – e.g. the 'final ritard' – to imitate properties of forces and friction in the natural world (Desain and Honing 1996 Honing 2003 Larson 2012). Within our framework, these are examples of triggers of semantic inferences, but there are many others as well. Thus our source-based semantics is intrinsically pluralistic, and may help unify these diverse insights.

1.3 Empirical situation

Numerous experimental results in music psychology show that some musical features are correlated with some inferential effects. Many, but not all, pertain to emotional inferences, as shown the review by Gabrielsson and Lindström 2010: diverse inferences are triggered by loudness, timbre, tempo, but also melody, harmony, intervals, etc. So what is gained by developing a theory of musical truth? Why not just list these correlations? And how does the proposed theory relate to these experimental results?

There are four theoretical benefits that one can expect from the present project. First, it will seek to *explain* the correlations that have been observed in terms of inferences one drawn on the basis of normal auditory cognition or of properties of tonal pitch space. Second, it will offer a way to *aggregate* these diverse inferences, something which need not be trivial when correlations are studied on a feature-by-feature basis. Third, for this reason it will make *new predictions* about how these features interact (a simple example will be given pertaining to the interaction of tempo and loudness). Fourth, it will display a non-trivial consequence of these multiple correlations – namely that they allow for a theory of musical truth.

Since our goals are primarily theoretical, we will not offer new experimental evidence for the correlations we rely on. But we will discuss numerous examples. Following the method of earlier theoretical attempts, notably Lerdahl and Jackendoff 1983, we will use introspective judgments on musical stimuli to motivate theoretical claims, and we will try to cite relevant experimental results that support these claims. Whenever possible, we seek to construct 'minimal pairs' in which one parameter is varied at a time so as to assess its specific role – a standard method in experimental psychology and also in linguistics. Important or controversial generalizations should then be tested with experimental means. This 'divide-and-conquer' strategy – build theories with introspective data, refine them later with experimental methods – is not an idiosyncracy of early works on music cognition. It is to this day the standard practice in theoretical linguistics, where the introspective method has proven valuable to construct sophisticated theories, and has been subjected to experimental validations, with good results (Sprouse and Almeida 2012, 2013, Sprouse et al. 2013).

1.4 Structure of this article

The rest of this article is organized as follows. In Section 2, we motivate our project by discussing an example of a semantic effect in music, based on inferences from normal auditory cognition and tonal properties. In Section 3, we list some types of inference drawn from normal auditory cognition, and we do the same thing for inferences from tonal properties in Section 4. In Section 5, we explain how both types of inference can be aggregated in a highly simplified theory of 'musical truth'. We then argue in Section 6 that the our semantic approach can account for some aspects of musical syntax, including cases in which tree structures turn out to be inadequate. Finally, we briefly argue in Section 7 that our 'referentialist' framework can still account for different types of emotional effects in music. Conclusions and questions for future research are listed in Section 8.

2 Motivating Music Semantics

2.1 The Null Theory: no semantics or an 'internal' semantics

A natural view is that music simply has no semantics, and that it is a formal system that does not bear any relation akin to *reference* to anything extra-musical. A slightly different view is that music has a semantics, but that it pertains to objects that are themselves musical in nature – what we will call an 'internal' semantics. In particular, Granroth-Wilding and Steedman 2014 endow their formal syntax for jazz chord sequences with a semantics that encodes *paths in a tonal pitch space*. In their analysis, surface chords can be assigned syntactic categories that give rise to derivation trees. Each derivational step in the syntax goes hand in hand with a semantic step, which encodes movements in tonal pitch space. Related intuitions are expressed by Lerdahl, who sometimes compares the meaning of music to a journey through tonal pitch space (see Lerdahl 2001). We also take Meyer's influential account of meaning and emotion in music to be based on an internal semantics. In his view, "one musical event (...) has meaning because it points to and makes us expect another musical event" (Meyer 1956, chapter I), which leads to expectations and emotions, and what Meyer calls 'embodied meaning'.

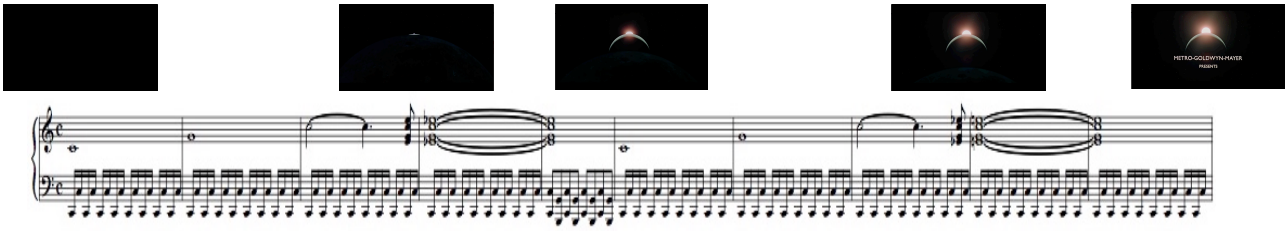
Importantly, such an 'internal' semantics is not what we wish to argue for. Rather, we will suggest that musical pieces come with a *bona fide* external semantics, albeit a highly underspecified one, and an associated notion of 'truth' in certain (real or imagined) situations. This does not preclude one from *also* exploring an internal semantics, but this is a very different enteprise. To take a linguistic analogy: sequences of a meaningless syllables (e.g. *la lu lu*, *li lu lu*, *lo lu lu*) could be made to follow some regular patterns and thus to trigger some expectations, which should yield a version of Meyer's embodied meaning. But this is entirely different from the notion of meaning one has studies the referential properties of meaningful words.

Since it is not quite standard to claim that music has a semantics in the ordinary sense (an external semantics, which conveys information about the world), we will first attempt to motivate it on the basis of some examples.

2.2 An example of semantic effects in music

We start with the beginning of Strauss's Zarathustra ('Sunrise') [https://www.youtube.com/watch?v=UH3IULiXo24], which is used as the sound track of the beginning of the movie *2001: a Space Odyssey* (sound example **S01**) [https://www.youtube.com/watch?v=e-QFj59PON4&t=0,14s]. In (1), we have superimposed some of the key images of the movie with a 'bare bones' commercial piano reduction (by William Wallace). The correspondence already gives a hint as to the inferences one can draw from the music.

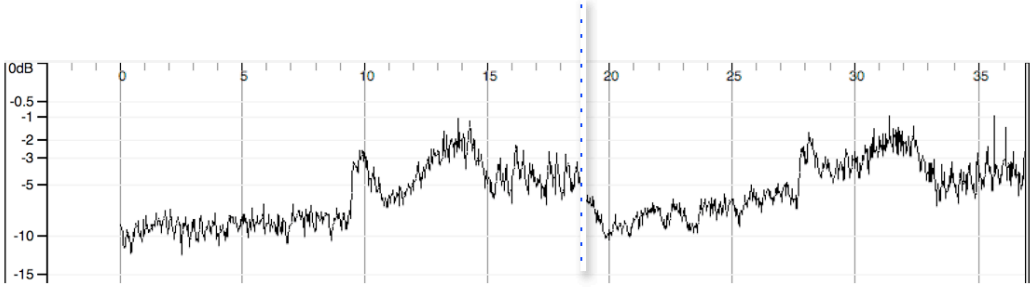
(1) Beginning of Strauss's Zarathutra, with the visuals of *2001: a Space Odyssey* (approximate alignment)
http://www.8notes.com/scores/7213.asp



Specifically, the film synchronizes with the music the appearance of a sun behind a planet, in stages – two of which are represented here. Bars 1-5 correspond to the appearance of the first third of the sun, bars 5-8 to the appearance of the second third (4-5 more measures are needed to complete the process – we simplify the discussion by focusing on the beginning). Now the music certainly evokes the development of a phenomenon in stages as well – which is unsurprising as it is an antecedent-consequent structure. But the music triggers more subtle inferences as well. A listener might get the impression that there is gradual development and a marked retreat at the end of the first part, followed by a more assertive development in the second part, reaching its (first) climax in bar 5. Several factors conspire to produce this impression. Three are mentioned in (2). In (2)a, we use chord notation to represent the harmonic development (with IM for a major I and Im for a minor I). In (2)b, we use numbers from 1 through 5 to represent the melodic movement among 5 different levels (with 1 = lower C, 2 = G, 3 = higher C, 4 = Eb, 5 = E). Finally, in (2)c we use standard dynamics notation to encode loudness, using the dynamics in a richer piano reduction by Schmalz.

(2) a. Harmony: I V I IM Im I V I Im IM
b. Melody (soprano) 1 2 3 5 4 1 2 3 4 5

c. Loudness: p f>> p< f< mf f>> p< f<



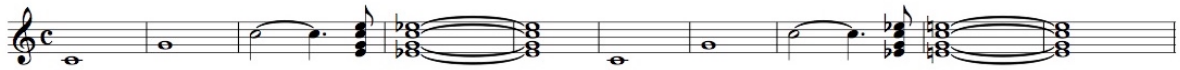
Harmonically, both the antecedent and the consequent display a movement from degrees I to V to I, but the antecedent ends with a I Major – I minor sequence, whereas the consequent ends with a I minor – I Major sequence. The I minor chord is usually considered less stable than the I Major chord. This produces the impression of a retreat at the end of the antecedent, as it reaches a stable position (I Major) and immediately goes to a less stable position (I minor); the end of the consequent displays the opposite movement, reaching the more stable position. *Melodically*, the soprano voice gradually goes up in the antecedent, but then goes down by a half-step at the very end – hence also an impression of retreat. Here too, the opposite movement is found at the end of the consequent. In terms of *loudness*, the antecedent starts piano (p), whereas the consequent starts mezzo forte (mf), hence the impression that the consequent is more assertive than the antecedent. Each gesture features a crescendo, which produces the impression of a gradual development. Finally, each gesture ends with a quick decrescendo followed by a strong crescendo, which may give the impression of a goal-directed development, with sharp boundaries in each case.

There would definitely be more subtle effects to discuss. But even at this point, it is worth asking whether harmonic and melodic movement are *both* crucial to the observed semantic effect, in

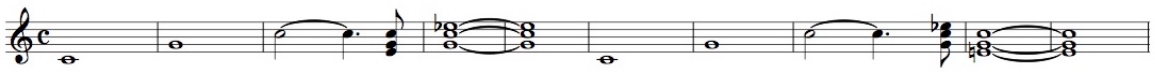
particular that the development retreats at the end of the antecedent. The question can be addressed by determining whether the effect remains when (i) the harmony is kept constant but the melodic movement of the soprano is removed, and (ii) the melodic movement is retained but the harmony is removed.

One way to test (i) is to remove notes responsible for the upward or downward melodic movement while keeping the harmony constant. This is done on the basis of the very simple piano reduction in (1), further simplified to (3)a. In (3)b, two (highlighted) E's responsible for the melodic movement were removed. The initial effect (unstable ending at the end of the antecedent, stable ending at the end of the consequent) is still largely preserved. This might in part be due to the fact that the harmonics of the remaining E's produce the illusion of the same melodic movement as before. But the semantic effect observed is arguably weakened when these remaining E's are lowered by one octave, as is seen in (3)c. While the effects are subtle, the comparison between these 'minimal pairs' suggests that although harmony plays an important role in the semantic effect we observe, the melodic movement might play a role as well.

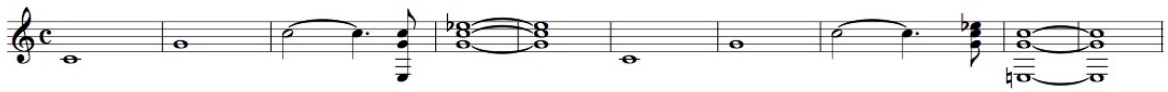
(3) a. A 'bare bones' piano reduction of Strauss's Zarathustra, measures 5-13 (= same as the reduction in (1), without lower voice)(sound example **S03a**)
https://soundcloud.com/philippeschlenker/strauss-zarathustra-2-10-standard-no-base?in=philippeschlenker/sets/prolegomena-to-music-semantics



b. Same as a., but removing notes responsible for the downward or upward movement of the soprano in a. (the notes that were removed are appear in red in a.)(sound example **S03b**)
https://soundcloud.com/philippeschlenker/strauss-zarathustra-2-10-no-mel-mvt-no-base

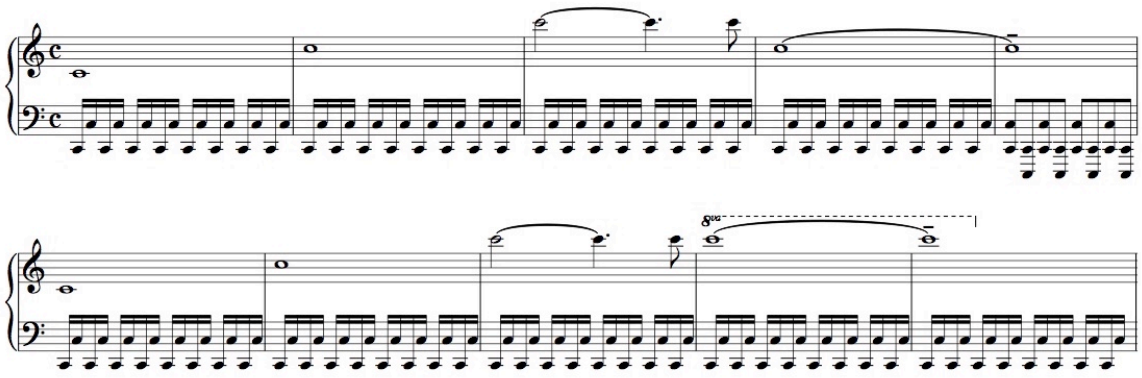


c. Same as b., but lowering by one octave the lower Es (in red)(sound example **S03c**)
https://soundcloud.com/philippeschlenker/strauss-zarathustra-2-10-no-mel-mvt-no-base-low-e?in=philippeschlenker/sets/prolegomena-to-music-semantics



The potential contribution of the melodic movement can be further highlighted by turning to (ii) and asking what effect is obtained if we rewrite (3)a so that only the note C is used, going one octave up or one octave down depending on the melodic movement. What is striking about the result is that it strongly preserves the impression of a two-stage development, with a retreat at the end of a first stage and a more successful development at the end. In this case we have not so much constructed a 'minimal pair' (since there are many differences between (4) and the reduction in (1)) as 'removed' one dimension of the piece, namely harmony. (This is more commonly done when one is interested in the rhythm of a piece without consideration to its tonal properties: one can simply remove the notes.)

(4) A version of (3)a re-written using only the note C (sound example S04)
https://soundcloud.com/philippeschlenker/strauss-zarathustra-2-10-all-c?in=philippeschlenker/sets/prolegomena-to-music-semantics



In sum, both harmonic and non-harmonic properties could conspire to yield a powerful effect in the case at hand, and their potential contributions can be isolated by rewriting the piece in various ways, although this does not tell us what is the respective role of these two effects. Still, why should one draw such inferences on the basis of loudness and (non-harmonic) pitch height? As a first approximation, we can note that in normal auditory cognition a source of sound can usually be inferred to have more energy if it is louder; and given a fixed source, if the frequency increases, so does the number of cycles per time unit, and hence also the level of energy (if the amplitude is constant). On the tonal side, normal auditory cognition will not be directly helpful to draw inferences, but it seems that stability properties of tonal pitch space are somehow put in correspondence with stability properties of real world events.

For concreteness, we introduced the issue of semantic inferences on the basis of intuitive judgments triggered by a well-known excerpt. But numerous experimental results, referenced below, also establish related facts. Thus Koelsch et al. 2004 show that musical excerpts can prime certain words but not others (e.g. an excerpt might prime 'wideness' rather than 'narrowness', while another does the opposite; and similarly for 'needle' vs. 'river [http://www.nature.com/neuro/journal/v7/n3/suppinfo/nn1197_S1.html]); furthermore, the brain signatures of this priming effect (N400) are thought to be characteristic of semantic priming. Eitan and Granot 2004 show that "most musical parameters significantly affect several dimensions of motion imagery", while Juslin and Laukka 2003 and Gabrielsson and Lindström 2010 survey numerous emotional effects triggered by various musical parameters.

The challenge in the following sections will thus be twofold. First, we should establish more systematically that inferences are indeed drawn on the basis of normal auditory cognition on the one hand, and of properties of movement in tonal pitch space on the other; we will attempt to do so in Sections 3 and 4. Second, we should develop a framework in which both types of inferences can somehow be aggregated; we will sketch one in Section 5.

3 Inferences from Normal Auditory Cognition

Heider and Simmel 1944 [https://www.youtube.com/watch?v=VTNmLt7QX8E] famously showed that abstract animations involving simple geometric shapes such as triangles and circles can be construed (given certain movements) as involving objects, and more specifically animate entities with goals and even personalities. As they write, "the movements of lines and figures are the stimuli; but these movements become anchored in a field of objects and persons and are interpreted as acts.". Despite its distance from normal auditory cognition, we will argue (following Bregman 1994) that music equally triggers inferences about objects that are posited as 'virtual sources' of the music. The analysis will leave open whether the sources should be taken to be animate or not, something that will be determined on the basis of the particular properties of the music under consideration (we come back in Section 7 to the special status of emotional inferences in music). When the sources are interpreted as being agents, it will follow that, as Maus 1988 argued, "a listener follows the music by drawing on the skills that allow understanding of commonplace human action in everyday life".

For brevity, we leave out of the present discussion cases of musical iconicity, in which a musical sequence resembles auditory properties of an event it evokes (for instance, a clarinet off-stage is used to evoke a cuckoo by way of a series of descending two-note sequences in Saint-Saëns's *Carnival* [https://www.youtube.com/watch?v=5LOFhsksAYw&t=10m35s]; while cannons and the Marseillaise are used to evoke retreating French armies in Tchaikovsky's *1812 Overture* [https://www.youtube.com/watch?v=ZrsYD46W1U0&t=12m39s]). Suffice it to say that these inferences are immediately captured by a source-based semantics, and thus that non-iconic effects are of greater theoretical interest. The other examples we will discuss are more challenging because the musical stimuli need not resemble any sounds produced by the virtual sources, as was illustrated in Strauss's musical evocation of a sunrise in (1).

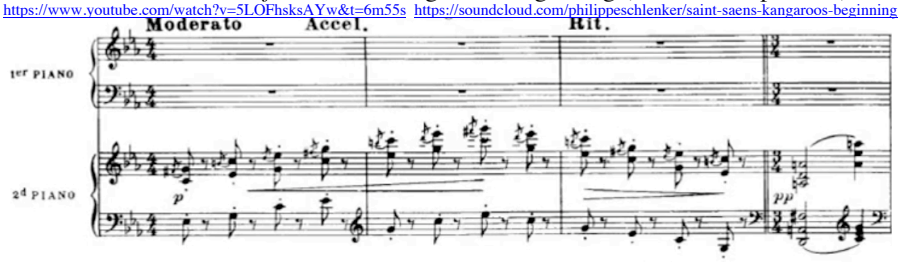
3.1 Sound and silence

Starting with the obvious, sound is taken to reflect the fact that something is happening to the source, while absence of sound is interpreted as an interruption of activity or the disappearance of the source. This entails that the number of sound events per time unit will give an indication of the rate of activity of the source. Importantly, the inferences one naturally derives from musical events are more abstract than those that normal audition would yield, since inferences may be drawn about virtual sources with no assumption that these sources produce sound (our formal account in Section 5 will capture this observation).

A very simple illustration of this effect can be found in Saint-Saëns's *Carnival of the Animals* (Saint-Saëns 1886), in the part devoted to kangaroos [https://www.youtube.com/watch?v=5LOFhsksAYw&t=6m55s]. When the first piano enters, it plays a series of eighth notes separated by eighth silences. This evokes a succession of brief events separated by interruptions. In the context of Saint-Saëns's piece, one can interpret these sequences as evoking kangaroo jumps: for each jump, the ground is hit, hence a brief

note, and then the kangaroo rebounds, hence a brief silence. The inferences obtained would be far more abstract if we did not have the title and context of the piece, but the main effect would remain, that of a succession of brief, interrupted events.

(5) Saint-Saëns's *Carnival of Animals,* Kangaroos, beginning (sound example **S05**)
https://www.youtube.com/watch?v=5LOFhsksAYw&t=6m55s https://soundcloud.com/philippeschlenker/saint-saens-kangaroos-beginning



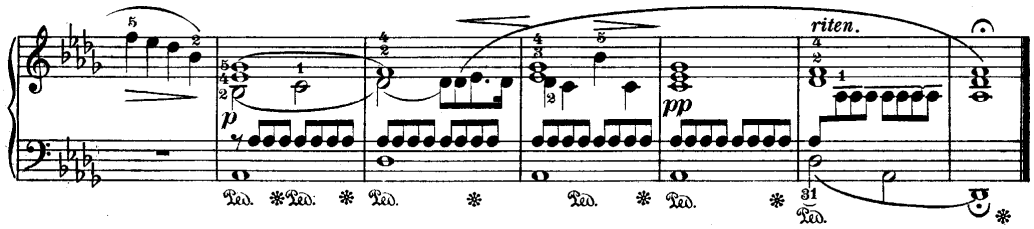
3.2 Speed and speed modifications

Since sound (as opposed to silence) provides information about events undergone by the source, changes in the speed of appearance of sound will be interpreted as changes in the rate of appearance of the relevant events. In the quoted piece on kangaroos (in (5)), each series of jumps starts slow, then accelerates, and then ends slow – and this produces the impression of corresponding changes of speed in the kangaroos' jumps (Eitan and Granot 2006 provide experimental data on the connection between 'inter-onset interval' and the scenes evoked in listeners).

The tempo of an entire piece can itself have semantic implications. An amusing example can be heard in Saint-Saëns's tortoises (sound example **S05.1**) [https://www.youtube.com/watch?v=5LOFhsksAYw&t=3m21s ; https://soundcloud.com/philippeschlenker/saint-saens-kangaroos-beginning]. It features an extremely slow version of a famous dance made popular in an opera by Offenbach (the 'infernal galop' [https://www.youtube.com/watch?v=5LOFhsksAYw&t=3m21s]). Saint-Saëns's version evokes very slow moving objects that attempt a famous dance at their own, non-standard pace. Similarly, Mahler's Frère Jacques (sound example **S05.2**) [https://soundcloud.com/philippeschlenker/mahler-frere-jacques-1-6-normal/s-cyGju] departs from the 'standard' Frère Jacques not just in being in minor key (and in some melodic respects), but also in being very slow – which is important to evoke a funeral procession. A version of a midi file in which the speed has been multiplied by 2.5 (sound example **S05.3**) [https://soundcloud.com/philippeschlenker/mahler-frere-jacques-1-6-speed25/s-OG4VF] loses much of the solemnity of Mahler's version (and it also sounds significantly happier – see Schlenker 2016 for discussion).

There are certainly more abstract effects associated with speed. In our experience of the non-musical world, speed acceleration is associated with increases in energy, and conversely deceleration is associated with energy loss (see Ilie and Thompson on the relation between speed and 'energy arousal'). This is probably the reason why it is customary to signal the end of certain pieces with a deceleration or 'final ritard' (see Desain and Honing 1996, Honing 2003). An example among many involves Chopin's 'Raindrop' Prelude, which features an 'ostinato' repetition of simple notes – which could be likened to raindrops hitting a surface. The last two bars include a strong ritenuto. Artificially removing it weakens the impression that a natural phenomenon is gradually dying out (for reasons we will come to shortly, there are several other mechanisms that also yield the same impression, hence just removing the speed change does not entirely remove the impression but just weakens it).

(6) Last bars of Chopin's Prelude 15 ('Raindrop')
a. The last two bars include a ritenuto (normal version)(sound example **S06a**).
https://soundcloud.com/philippeschlenker/chopin-prelude-15-last-2-bars-normal



b. A modified version of a. with constant speed in the last two bars does not yield the same impression of a phenomenon gradually dying out (sound example **S06b**).
https://soundcloud.com/philippeschlenker/chopin-prelude-15-last-2-bars-no-rit

A hypothesis of great interest in the literature is that the precise way in which a final ritard is realized follows laws of human movement within a physical model with a braking force (see Honing 2003, who introduces his idea by way of a mechanical machine that realizes a ritard [https://youtu.be/yxj5Wfp4bxQ]).

In addition, sources that are analyzed as being animate can be thought to observe an 'urgency code' by which greater threats are associated with faster production rates of alarm calls (e.g.

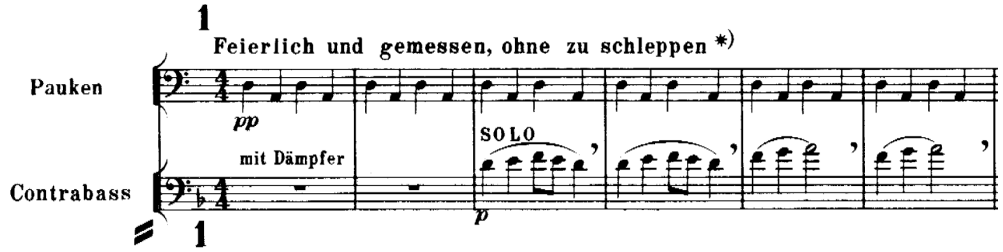
Lemasson et al. 2010). This presumably accounts for the association of greater speeds with greater arousal, although this would require a separate musical and ethological discussion.

While the meaning of music has often been analyzed in connection with *movement* (e.g. Clarke 2001, Eitan and Granot 2006, Godoy and Leman 2010, Larson 2012), in the general case we will make use of the weaker notion of *change* because music may be interpreted in terms of internal experiences, as we will see in our discussion of musical emotions in Section 7.

3.3 Loudness

A sound that is becoming louder could typically be interpreted in one of two ways: either the source is producing the sound with greater energy, or the source is approaching the perceiver. As Eitan and Granot 2006 write, while "dynamic changes are mostly produced by changes in the energy of the emitted sound", a listener might still "metaphorically relate musical loudness to distance, given a lifelong experience of relating the two features in nonmusical contexts". The first case is of course pervasive in music (for experimental results, see for instance Ilie and Thompson 2006). The second case can be illustrated by manipulating the loudness of a well-known example. The beginning of Mahler's (minor version of) Frère Jacques (First Symphony, 3rd movement) starts with the timpani giving the beat, and then the contrabass playing the melody, all pianissimo, as shown in (7)a. One can artificially add a marked crescendo to the entire development – and one plausible interpretation becomes that of a procession (possibly playing funeral music, as intended by Mahler) which is gradually approaching.

(7) Mahler's Frère Jacques (First Symphony, 3rd movement)
a. Beginning, normal version (sound example **S07a**)
https://soundcloud.com/philippeschlenker/mahler-frere-jacques-1-6-normal-1



b. Beginning, with an artificially added crescendo: this can yield the impression that a procession is approaching (sound example **S07b**)
https://soundcloud.com/philippeschlenker/mahler-frere-jacques-1-6-crescendo-beg

c. End: depending on the realization, the decrescendo might be indicative of a procession moving away (sound example **S07c**)
https://soundcloud.com/philippeschlenker/mahler-frere-jacques-last-6-normal

Without any manipulation, the end of Mahler's Frère Jacques displays a decrescendo that can probably be interpreted as the source gradually losing energy, but which can also plausibly be construed as a procession moving away from the perceiver ((7)c).

Interestingly, just looking at the interaction between speed and loudness, we can begin to predict how an ending will be interpreted. As noted, a diminuendo ending can be interpreted as involving a source moving away, or as a source losing energy. In the former case, one would not expect the perceived speed of events to be significantly affected. In the second case, by contrast, both the loudness and the speed should be affected. The effect can be tested by exaggerating the diminuendo at the end of Chopin's Raindrop Prelude in (7); without the ritenuto, the source is easily perceived as moving away. [1]

(8) Last bars of Chopin's Prelude 15 ('Raindrop')
a. Exaggerated version of the diminuendo in the normal version, with a ritenuto (sound example **S08a**)
https://soundcloud.com/philippeschlenker/chopin-prelude-15-last-2-bars-normal-dim
The source seems to gradually lose energy, becoming slower and softer.
b. Same as a., but without ritenuto (sound example **S08b**)
https://soundcloud.com/philippeschlenker/chopin-prelude-15-last-2-bars-no-rit-dim
The source seems to be moving away, as it gradually becomes softer, without change of speed.

This type of prediction highlights the importance of a semantic framework that postulates a virtual source behind the music, and simultaneously studies all the inferences that it may trigger. In the case

[1] If we add a crude crescendo instead, and a final accent, the ending sounds more intentional, as if the source gradually gained stamina as it approaches its goal, and signals its success with a triumphant spike of energy (sound example **S07.1**) [https://soundcloud.com/philippeschlenker/chopin-prelude-15-last-2-bars-cresaccent]. An intentional, triumphant effect is often produced by fortissimo endings, e.g. at the end of Beethoven's Symphony 8 (sound example **S07.2**) [https://www.youtube.com/watch?v=C2Avpt9FKP0&t=26m10s; https://soundcloud.com/philippeschlenker/beethoven-8th-symphony-end].

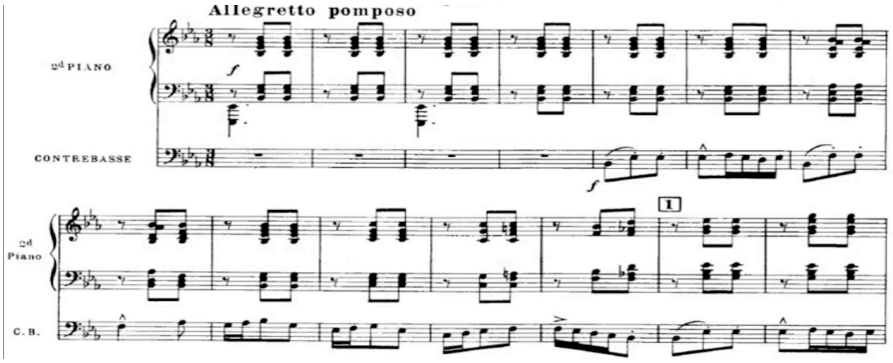
at hand, it is because of properties of sound sources in normal auditory cognition that a diminuendo realized with a ritenuto naturally gives rise to an interpretation in terms of gradual loss of energy, whereas a diminuendo without a ritenuto can be interpreted as the source moving way.

3.4 Pitch Height

Pitch plays a crucial role in the tonal aspects of music. But keeping the melody and harmony constant, pitch can have powerful effects as well, which we take to be due to the inferences it licenses about the (virtual) source of the sound. Two kinds of inferences are particularly salient.

(i) The register of a given source – especially for animals – provides information about its size: larger sources tend to produce sounds with lower frequencies (as Cross and Woodruff 2008 note, this correlation lies at the source of a 'frequency' code', discussed in linguistics by Ohala 1994, according to which lower pitch is associated with larger body size). This is a sufficiently important inference that some animals apparently evolved mechanisms – specifically, laryngeal descent – to lower their vocal-tract resonant frequencies so as to exaggerate their perceived size (Fitch and Reby 2001). The relevant inference is put to comical effect in Saint-Saëns's Carnival, where the melody of a dance is played with a double bass to figure an elephant [https://www.youtube.com/watch?v=5LOFhsksAYw&t=5m24s]. The specific effect of pitch, keeping everything else constant, can be seen by comparing Saint Saëns's version (in a midi rendition, as in (9)a) to an artificially altered version in which the double bass part was raised by two octaves. The impression that a large animal is evoked immediately disappears. If the double bass part is raised by 3 octaves, we even get, if anything, the evocation of a small source (as in (9)c).

(9) Saint-Saëns's Carnival of Animals, The Elephant, beginning
a. The normal version features a double bass to evoke a large animal (sound example **S09a**).
https://soundcloud.com/philippeschlenker/saint-saens-carnival-elephant-normal



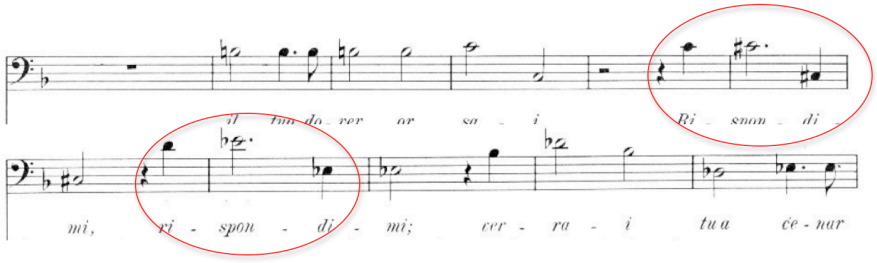
b. Raising the double bass part by 2 octaves (while leaving the piano accompaniment unchanged) removes the evocation of a large source (sound example **S09b**).
https://soundcloud.com/philippeschlenker/saint-saens-carnival-elephant-2-oct

c. Raising the double bass part by 3 octaves might even evoke a small rather than a large source (sound example **S09c**).
https://soundcloud.com/philippeschlenker/saint-saens-carnival-elephant-3-oct

(ii) For a given source, higher pitch is associated with a source that produces more events per time units, hence might have more energy or be more excited; Ilie and Thompson 2006 provide experimental evidence for an association between higher pitch and greater 'tension arousal' ('tense' vs. 'relaxed').We already saw an instance of this effect in the version rewritten only with C notes of the beginning of Strauss's *Zarathustra* in (1). A chromatic ascension with repetition is also used in the Commendatore scene of Mozart's Don Giovanni to highlight the increasingly pressing nature of the Commendatore's order: *rispondimi! rispondimi!* ('answer me! answer me!'; it probably tends to be produced crescendo, which of course adds to the effect).

(10) Mozart's Don Giovanni, Commendatore scene, 'Rispondimi': repetition is produced with a chromatic ascent, which contributes to the impression that the Commendatore's request is becoming more pressing (sound example **S10**).

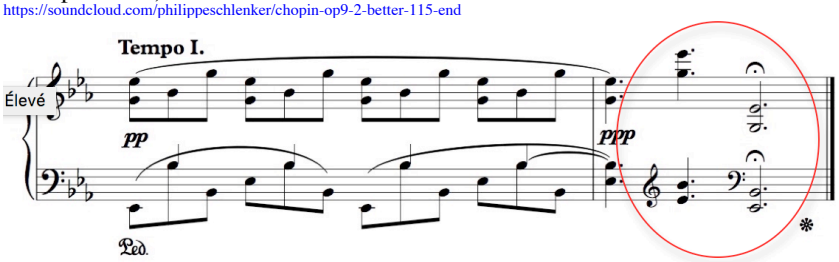
https://www.youtube.com/watch?v=dK1_vm0FMAU&t=3m19s https://youtu.be/aqwr9QMBthU



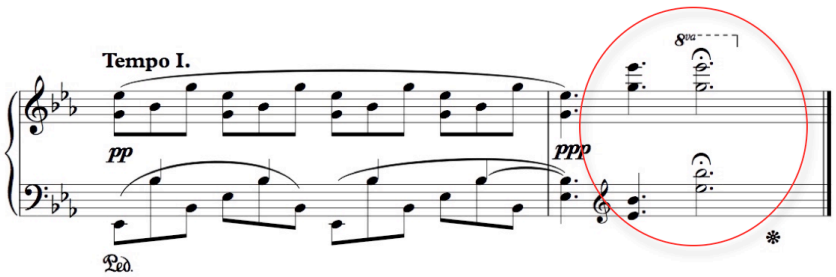
If these remarks are on the right track, all other things being equal, the end of a piece should sound slightly more conclusive if the last melodic movement is downward rather than upward. This effect can be found at the end of Chopin's Nocturne Op. 9/2, which ends with two identical chords, except that the second is 2 octaves below the first. If the score is re-written so that the piece ends upwards rather than downwards, the effect is a bit less conclusive, as is illustrated in (11).

(11) Chopin's Nocturne Op. 9/2, last two measures

a. The original version ends with two identical chords, the second one 2 octaves below the first one (sound example **S11a**).
https://soundcloud.com/philippeschlenker/chopin-op9-2-better-115-end



b. If instead the second chord is raised by 3 octaves and thus ends up being 1 octave above the first one, the effect is less conclusive (sound example **S11b**).
https://soundcloud.com/philippeschlenker/chopin-op9-2-better-115-end-3-octaves-up



Larson 2012 defines a principle of 'melodic gravity' to capture the "tendency of notes above a reference platform to descend" – which comes very close to what an energy-based interpretation of pitches would lead one to expect as a default pattern, i.e. without the intervention of further forces (ones that are analyzed within Larson's theory of 'musical forces'). Similarly, Larson defines a principle of 'musical inertia', defined as the "tendency of pitches or durations, or both, to continue in the pattern perceived" (a more harmonic principle of 'melodic magnetism' is briefly mentioned in Section 4). Importantly, these are not primitives in the present analysis: when pitch differences trigger inferences about the changing level of energy of a given source, our knowledge of the world will be sufficient to trigger the expectation that, under specific circumstances (and in particular in the absence of external, non-musical forces), the level of energy of that source should go down. Similarly, world knowledge might lead us to expect that, as a default, things might continue to behave as they did (with decreasing energy if 'friction' matters). These effects might be quite real, but on the present view they result from the interaction of music semantics with world knowledge rather than from primitive musical principles.

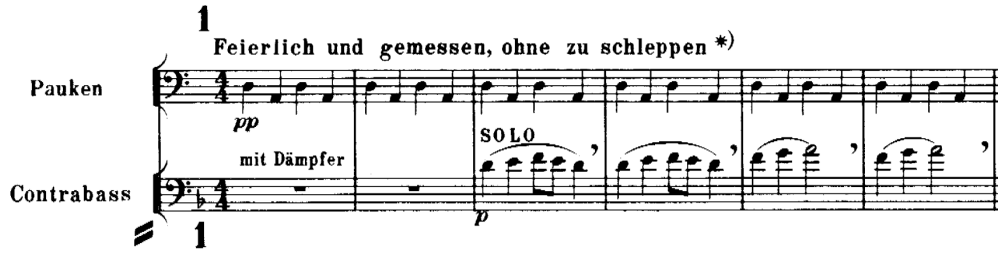
3.5 Interaction of properties

Rather than delving more deeply into a topic we must leave for future research, we will give one example that involves several factors at once. Consider repetitions. Performers know that any repeated motive leads to crucial decisions concerning its execution. In fact, we already saw several relevant examples.

The last notes of Mahler's Frère Jacques involve a repetition with attenuation of the loudness, and in a standard version (sound example **S11.1**) [https://soundcloud.com/user-985799021-177497631/mahler-frere-jacques-last-6-normal/s-qCUPT] they could be interpreted in terms of a source moving away, or gradually dying out. But if a strong rallentando is added (sound example **S11.2**) [https://soundcloud.com/user-985799021-177497631/mahler-frere-jacques-last-6-ralent/s-qdHOL], the 'moving away' interpretation becomes less likely, and the 'dying out' interpretation becomes more salient – which is exactly the effect we discussed in connection with the end of Chopin's Raindrop Prelude in (11).

We can also manipulate the beginning of Mahler's Frère Jacques to modify the interpretation of the initial repetitions. A repetition which is realized far more softly that its antecedent may sound like an echo of it, as in (12)b. A louder realization of the repetition may be interpreted as re-assertion, or possibly as a dialogue between two voices, as in (12)c.

(12) Mahler's Frère Jacques (First Symphony, 3rd movement)
a. Beginning, normal version (sound example **S12a**)
https://soundcloud.com/user-985799021-177497631/mahler-frere-jacques-3-6-normal/s-10XsM



b. If measures 4 and 6 are realized far less loudly than measures 3 and 5, one can obtain the impression of an echo, or of a dialogue between two voices, one of which is in the distance (sound example **S12b**).
https://soundcloud.com/user-985799021-177497631/mahler-frere-jacques-3-6-echo-30/s-CxzyO

c. If measures 4 and 6 are realized far more loudly than measures 3 and 5, one can also obtain the impression of a dialogue between two voices, or one can get the impression that measures 3 and 5 are reasserted more strongly by the same voice (sound example **S12c**).
https://soundcloud.com/user-985799021-177497631/mahler-frere-jacques-3-6-echo30/s-zXeUA

The key is that in nature repetitions are rarely the product of chance. Depending on how they are realized, they may yield the inference that a phenomenon is naturally repeating itself, often with loss of energy and thus attenuation – unless the source is approaching the perceiver, in which case the perceived level of energy may increase. Alternatively, the source may be intentional and may be reiterating an action that was not initially successful, possibly with more energy than the first time around. Yet another possibility is that one source is imitating another, hence the impression of a kind of dialogue. The typology will no doubt have to be enriched.

3.6 Methods to test inferences from normal auditory cognition

Our list of inferences drawn from normal auditory cognition is only illustrative, and ought to be expanded in future research. We believe that such inferences could be tested with the following method (see Eitan and Granot 2006 for more specific methods designed to test the relation between music and movement).
1. First, a clear hypothesis should be stated – for instance that, all other things being equal, a given source will be inferred to have greater energy when it produces a higher than a lower sound.
2. Second, minimal pairs should be constructed to assess the inference in a musical context. This could be done in two ways. One may select actual musical examples, and manipulate them so as to get contrasting pairs, as we did with the end of Chopin's Nocturne 9/2 (in (11)). Alternatively, one may create artificial stimuli which also display a minimal contrast with respect to the relevant parameter, but might be simpler than 'real' music, as we did in our discussion of a pure C-version of Strauss's Zarathustra (in (4)).

In each case, one should state a target inference about the source, and determine whether it is triggered more strongly by one stimulus or by the other. One may test the target inference by way of abstract statements in natural language – e.g. Which of these two pieces sounds more conclusive? or: Which of these two pieces evokes a phenomenon with the greater level of energy? Or one could resort to indirect ways of testing the inference, for instance by having subjects match musical stimuli with non-musical scenes (e.g. visual ones). Which types of statements will prove most productive is entirely open as things stand, and it is likely that different methods will have to be developed depending on the particular goals of the research. Finally, semantic intuitions might be sharpened by initially restricting the set of models the subjects consider. This is in effect what program music and sometimes just titles do. For instance, one may tell subjects that a piece represents the movement of

the sun, and ask them what they infer about that movement at various points in the development of the piece.
3. Third, one will have to show that these inferences are genuinely triggered in non-musical cognition as well. This may be done by creating non-musical stimuli – for instance with noise, or in some cases with human voices or even with animal calls – that make it possible to test the parameter under study. In some cases one may even go further and suggest that the relevant properties exist across modalities, and have a counterpart in visual cognition.
4. Finally, as we briefly suggested in our discussion of endings and repetitions, a source-based semantics will prove particularly useful when the interaction of several properties is explored, as the inferences will become much richer in that case.

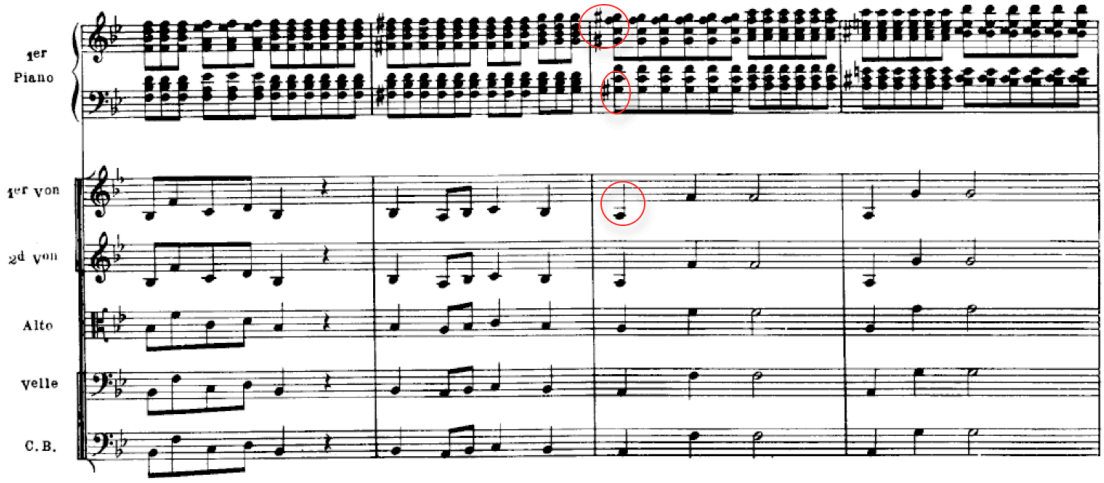
4 Inferences from Tonal Properties

Lerdahl 2001 makes reference to Heider and Simmel's (1944) experiment, cited above, "in which three dots moved so that they did not blindly follow physical laws, like balls on a billiard table, but seemed to interact with another – trying, helping, hindering, chasing – in ways that violated intuitive physics", and thus were perceived as animate agents. Lerdahl argue that similar effects arise in music: "here the dots are events, which behave like interacting agents that move and swerve in time and space, attracting and repelling, tensing and coming to rest". Importantly, for him these inferences arise at least in part on the basis of the behavior of voices in tonal pitch space. Relatedly, Larson 2012 develops a theory in which the semantic effects of music are analyzed in terms of motion, but within a universe with 'musical forces' that are based in part on harmonic considerations (notably, a principle of 'melodic magnetism', which is "the tendency of unstable notes to move to the closest stable pitch" (p. 2)). Since tonal properties do not have a complete equivalent in normal auditory cognition – unlike loudness, say – we must complement our initial list of inferences with ones that are specifically drawn on the basis of tonal properties. The challenge (to be addressed in Section 5) will be to develop a method to aggregate these heterogeneous inferences. (While tonal inferences can only be understood in the context of the formal properties of tonal pitch space, they might well be *grounded* in some properties of normal auditory cognition, for instance in animal signals, human voices, or more general inferences relating consonance/dissonance to properties of the source; we briefly discuss some possibilities at the end of this section.)

4.1 An example: a dissonance

A very simple example will help illustrate the inferential power of tonal inferences. In Saint Saëns's very slow version of the *Can Can* dance, which he uses to represent tortoises, there are moments of severe dissonance, and they produce a powerful effect. The very slow dance evokes the tortoises' slow walk. But when we hear a dissonance in measure 12, copied in (13), we get the impression that the tortoises are tripping on something. In the words of the Calgary Philharmonic Education Series, the dissonances "evoke the scene of lumbering turtles trying to dance and haplessly tripping over their feet." While at first it may seem that the musicians are out of tune, in fact they are just playing a dissonant chord, with both A and G# in the same chord, as shown in (13). When the G# is replaced with A throughout this half-measure (as in (13)b), the dissonance disappears, as does the impression that the tortoises are tripping.

(13) Saint Saëns, Carnival of Animals, Tortoises, measures 10-13 (sound example **S13**)
https://www.youtube.com/watch?v=5LOFhsksAYw&t=4m19s https://soundcloud.com/philippeschlenker/saint-saens-tortoises-dissonance



a. In the original version, there is a dissonance in the first half of measure 12 because a chord F A C is played with an G# added (as can be heard by focusing only on the violin and piano parts, for instance; sound exampe **S13a**).
https://soundcloud.com/philippeschlenker/saint-saens-carnival-tortoises-12-13-normal-piano-51

b. The dissonance can be removed by turning the G#'s into A's – and the impression that tortoises disappears (as can be heard by focusing only on the violin and piano part, for instance; sound example **S13b**).
https://soundcloud.com/philippeschlenker/saint-saens-carnival-tortoises-12-13-corrected-piano-51

In this very simple example, a point of great *tonal* instability is interpreted as corresponding to an event of great *physical* instability for the tortoises, which correspond to the virtual sources of the voices. In the general case, things are far less specific. In fact, if we disregarded Saint Saëns's title, the inferences we draw would not specifically be about tortoises, but they would probably still involve a source which is slow (due to the comparison with the speed of the standard *Can Can*), and also in positions of instability at moments that correspond to the dissonances (this would be *compatible* with the tortoise-related interpretation, but far less specific).

4.2 Cadences

In traditional music theory, a cadence is the standard way of marking the end of a classical piece, typically by way of a dominant chord (V) (often preceded by a preparation in a 'subdominant' region of tonal pitch space), followed by a tonic chord (I). In addition, there are 'half-cadences' ending on a dominant chord, which can signal temporary pauses and call for a continuation. These devices play a central role in analyses of musical syntax, as in Lerdahl and Jackendoff 1983, and Rohrmeier 2011 (for whom the role of cadences is 'hard-wired' in rules of 'functional expansion').

The question that is not fully addressed in these syntactic frameworks is *why* certain sequences of chords are used to mark a weak or a strong end. We submit that the traditional intuition, framed in terms of relative stability, is exactly right but needs to be stated within a semantic framework. In brief, a full cadence is final because it ends in a position of tonic space that is maximally stable. A half-cadence is less final because it ends in a position that is relatively stable, but less so than a tonic. Furthermore, cadences are often of the form subdominant - dominant - tonic because this provides a gradual path towards tonal repose, assuming that the hierarchy of stability of chords is IV < V < I; this mirrors one of the patterns we saw with speed and loudness, both of which could be decreased gradually to signal the end of a piece. A semantic analysis could in principle capture these facts as follows: music is special (compared to non-musical sounds) in that the sources are understood to exist in a space with very special properties, isomorphic to those of tonal pitch space. In particular, different positions in tonal pitch space come with different degrees of stability, and relations of attraction to other positions. As a result, a source can be expected to be in a very stable position if it manifests itself by a tonic chord, and in a less stable, but still relatively stable position, if it manifests itself by a dominant.

Of course this only scratches the surface of an analysis of cadences. Still, the general form of the account seems appropriate to account for more fine-grained phenomena. To mention just two standard ones:

• A cadence is more conclusive if the final tonic chord is in root than in inverted form. This is presumably because in the former case the chord is more stable.

• If the final I chord is replaced with a VI chord (which shares with it 2 out of three notes – e.g. C E G vs. A C E), the result is less stable – hence the term of a 'deceptive cadence'.

Rich experimental results are relevant as well. Thus Rosner and Narmour 1992 systematically assessed the relative closure of chord progressions in naive subjects. They found clear differences across chord types, with V-I sequences assessed as more closed than all other progressions, in particular III-I, VI-I, or the plagal cadence IV-I. Progressions were generally assessed as more closed when the root was in bass position. Thus the general claims of traditional music theory seem to be empirically legitimate.

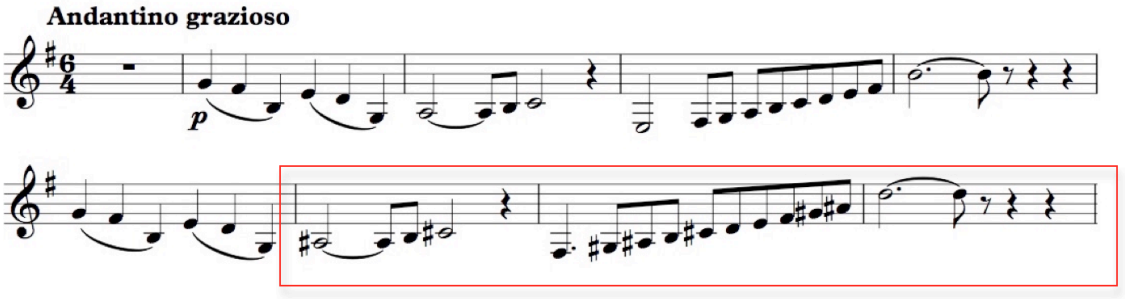
While the topic of cadences is a staple of music analysis, which the foregoing remarks just recapitulate, we believe that they should be studied within a broader framework in which considerations of harmonic stability are investigated in tandem with more or less conclusive effects produced by loudness, speed, melodic line, etc. These various parameters provide different sorts of semantic information: we already saw that loudness and speed modifications trigger different inferences, and that they can be combined to yield the effect that a source is gradually dying out or moving away. This typology should be enriched by considering how various types of cadences, which provide information about the stability of the positions reached, interact with the inferences triggered by loudness and speed, pitch, rhythm, etc. This is certainly not a new idea – for instance, Schenker's influential theory took not just harmonic progression but also a descending melodic 'fundamental line' to be part a complete tonal work (e.g. Forte 1959).

4.3 Modulations

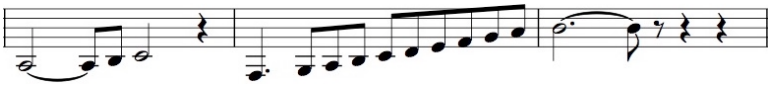
As is also well-known, tonal pitch space is organized into regions, which correspond to keys – with relations of distance among those. Modulation is often discussed through the metaphor of a move to a new location (Saslaw 1996), which may be more or less distant depending on the nature of the modulation (Thompson and Cuddy 1992 provide evidence that listeners with moderate musical training are indeed sensitive to the distance between keys in modulations). While experimental evidence would be needed to establish this point, we submit that moving to another key triggers the inference that the source is moving towards a new environment (or possibly that one starts perceiving a new source). Furthermore, key change is usually governed by rules of 'modulation', with transitional regions that belong to both keys. This can be seen as a constraint of continuity on possible movements of the sources: a jump to a distant key would be understood as being odd because it would violate this principle.

A simple example of a spatial interpretation of a modulation can be found in Saint-Saëns's Swan. The title as well as the initial undulating harp accompaniment are evocative of a movement on water – given the title, that of a swan. The piece is initially G Major but modulates to B minor in measures 7-10, as seen in (14)a. The effect is arguably to suggest the exploration of an area with a different type of landscape. This effect largely disappears if the modulations are rewritten in G Major, as is done in different ways in (14)b-c.

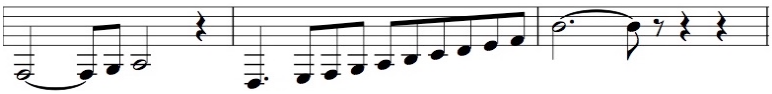
(14) Saint-Saëns, The Swan, initial modulation (b. and c. re-written by A. Bonetto)
a. Original version, in G major, with a modulation in B minor in measures 7-10 (sound example **S14a**)
https://soundcloud.com/philippeschlenker/saint-saens-cygne-normal



b. Pure G Major version, with measures 7-9 rewritten by eliminating alterations foreign to G Major, and replacing the final D with a B to avoid a jump of a fifth between the penultimate and last note (sound example **S14b**)
https://soundcloud.com/philippeschlenker/saint-saens-cygne-v1



c. Pure G Major version, with measure 7-9 rewritten by transposing down (by a third) what is written in B minor; this makes it possible to keep the same melody as in a., one third lower, but in G Major (sound example **S14c**)
https://soundcloud.com/philippeschlenker/saint-saens-cygne-v2



Both rewritten versions preserve the character of a movement, but what gets lost is the impression that a new type of landscape is being explored in measures 7-8.

4.4 Methods and further questions

Having sketched some very simple semantic effects that are triggered by tonal properties of music, we should add a word about the methods that could be employed to investigate them. In the study of inferences from normal auditory cognition (in Section 3), we could (i) select a semantic effect triggered by a certain property X of the music, and (ii) argue that X gives rise to similar inferences with non-musical stimuli. But because of what tonality is, part (ii) is not applicable in the present case. So the analysis must *per force* be more theory-internal. We thus propose that it should include the following steps.
1. First, a hypothesis should be stated – for instance that the leading tone is 'attracted' to the tonic and thus creates an expectation that a voice in the leading tone will then reach the tonic.
2. Second, minimal pairs should be constructed to establish the point. The general methods developed in experimental studies of music could presumably play a role here. In particular, intuitions could be made sharper by restricting the set of models of the music by specifying – by way of a title or a description – what the music is supposed to be about, and then testing semantic inferences that arise given this assumption (this is precisely what Saint-Saëns's title *The Swan* does in the case we just discussed).
3. Third, instead of correlating these effects with ones that are found in non-musical stimuli, one could seek to explain these effects by properties of tonal pitch space as analyzed (on non-semantic grounds) by the best experimental and formal studies.

Still, although some of the key properties of tonal pitch are not commonly found in normal auditory cognition, one should at some point ask whether normal auditory cognition motivates some of the general inferences we draw on the basis of tonal pitch space. We argued that a strong dissonance in tonal pitch space – as in Saint-Saëns's Tortoises – can easily be mapped to an instability in the normal, physical space. But what is the basis for this general inference? It would be interesting to investigate inferences that highly dissonant sounds give rise to in *normal* auditory cognition, and possibly use this to motivate the way in which detailed properties of tonal pitch space are semantically interpreted (from this, it does not follow that one could somehow do without the properties of tonal pitch space in stating a music semantics). This requires an understanding of the acoustic basis of consonance and dissonance, which has been studied in detail (e.g. McDermott et al. 2010); but also of

its correlates in the natural world. It must be said, however, that the experimental literature usually focuses exclusively on the connection between tonal properties and *emotions* (a topic we revisit in Section 7). For instance, Bowling et al. 2010 compare American speech and music, and show that "the spectral characteristics of excited speech more closely reflect the spectral characteristics of intervals in major music, whereas the spectral characteristics of subdued speech more closely reflect the spectral characteristics of intervals that distinguish minor music" (see also Bowling et al. 2012). For his part, Cook 2007 argues that the emotional effect of minor vs. major chords is related to Ohala's 'frequency code' (e.g. Ohala 1994), according to which animal dominance is expressed with low and/or falling pitch (Cook's proposed connection is that "tension triads resolve to minor chords with a semitone increase and to major chords with a semitone decrease"). Going in a somewhat different direction, Blumstein et al. 2012 show that adding distortion noise (nonlinearities) in a music piece induced in listeners an effect of "increased arousal (i.e. perceived emotional stimulation) and negative valence (i.e. perceived degree of negativity or sadness)". It is thus fair to say that the direct connection we propose to establish between tonal stability and the stability of *external events* denoted by the music has yet to be tested empirically.

5 Musical Truth

Following in part the literature, we have argued that music can give rise to inferences drawn from normal auditory cognition, and also to tonal inferences. We will now sketch a formal framework in which they can be integrated. This matters for three reasons. First, the inferences we displayed are abstract, and one must state precisely how they are drawn. For instance, in our discussion of Saint-Saëns's Kangaroos, we argued that a source-based semantics can explain why a series of eighth notes separated by eighth silences can evoke a succession of brief events separated by interruptions. But certainly the source-based semantics should not lead to the absurd inference that *kangaroos* are producing these notes – or sounds, for that matter. Rather, something more abstract is inferred from the music, namely that there was a quick succession of discrete events; all sorts of events, whether sound-producing or not, will satisfy this abstract inference. Second, the inferences we discussed interact with each other in non-trivial ways. As we saw in Section 3.5, a repetition with attenuation may be interpreted as a source dying out or moving away, but the former interpretation seems to become more likely when a rallentando is added. The key is that objects that move away without losing energy are unlikely to slow down, contrary to objects that are losing energy. We must thus find a systematic way to integrate these diverse inferences with one another, and also with world knowledge. Third, a systematic framework for musical inferences will turn out to yield a natural notion of 'musical truth', which is of some interest in its own right.

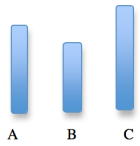
5.1 Inferences and interpretations

In view of the existence of inferences from normal auditory cognition as well as from tonal properties, the main challenge is to define a framework that can aggregate them despite their heterogeneity. In principle, this could be done in two ways:
1. **Inferential direction:** we could find a way to simply conjoin all the relevant inferences – and say that *the meaning of a musical piece is the set of inferences it licenses on its sources*.
2. **Model-theoretic direction:** alternatively, we could find a way to explain what it means for a musical piece to be *true* of a situation (or 'model').

An advantage of the second method is to ensure that the inferences licensed are not contradictory: by providing a situation that makes all of them true, we can be sure that we are not dealing with a system that is trivial because it licenses contradictions (we set aside the case of auditory illusions with a contradictory content). Still, it is often more intuitive to speak of the meaning of music in inferential terms, and it should be emphasized that inferential information will not be lost if we follow the second method. This is because the model-theoretic direction will specify for each musical piece a set of situations (possibly a very large set of very diverse situations) that make it true; the inferences licensed by the music will simply be the properties that are true of all of these situations.

Under what conditions will a musical piece be true of a situation? We will take musical events to depict events undergone by virtual sources. And we will take a series of musical events to be true of a series of real world events if certain relations among notes or chords correspond to designated relations among events; for instance, a louder note should correspond to a real world event which has greater energy or is closer; a more consonant chord should correspond to a more stable real world event, etc. The basic mechanism can be illustrated in a different domain by considering simplified pictorial representations, seen as visual depictions of certain objects. An example is given in (15), where three columns of various heights (A, B, C), arranged from left to right, are used to depict individuals as in the real world scenes in (16), involving a boy, a nurse and business woman.

(15) A pictorial representation



(16) Three possible denotations for (15)

a. 

b. 

c. 

We focus on two relations among the columns that appear in (15): 'is to the left of' (from our perspective), and 'is taller than'. At a very coarse-grained level, we can say that an assignment of values (namely real-world individuals) to the columns makes the picture *true* in a certain scene if these two relations are preserved.

Consider the assignment A → boy, B → nurse and C → businesswoman in the scene (16)a. In (15), A is to the left of B, which is to the left of C; the same relations hold of the denotations in the scene, since the boy is to the left of the nurse, who is to the left of the business woman. Thus the relation 'is to the left of' is preserved. Similarly for the relation 'is taller than': C is taller than A, which is taller than B. The same relation holds of the denotations, since the businesswoman is taller than the boy, who is taller than the nurse. Thus we can say that on this assignment of values to the columns, the pictorial representation in (15) is true of (16)a. By contrast, the assignment A → nurse, B → boy and C → businesswoman would fail to preserve the relation 'is to the left of', since (from our perspective) A is to the left of B in (15), but the nurse is not to the left of the boy in (16)a.

On the assignment A → nurse, B → boy and C → business woman, the relation 'is to the left of' in (15)(16) is preserved in scene (16)b. But the relation 'is taller than' is not preserved: while A is taller B, the denotation of A, the nurse, is not taller than the denotation of B, the boy, hence on this assignment (15) is not true of scene (16)b (in fact, no assignment of denotations could preserve both 'is to the left of' and is 'taller than' in this case).

The same type of problem arises for (16)c on the assignment A → business woman, B → boy and C → nurse: the relation 'is to the left of' is preserved, but the relation 'is taller than' is not, because C is taller than B but the nurse is not taller than the boy. Hence on this assignment (15) is not true of (16)c (nor could any assignment preserve both 'is to the left of' and 'is taller than').

We will apply the same type of definition of truth to musical pieces, but with relations that are more abstract than those involved in this simple pictorial example; in addition, since musical pieces are dynamic, something like the relation 'is to the left of' will be played by the relation 'temporally precedes'.. In the pictorial example, one may well investigate more fine-grained conditions of preservation, for instance involving the *proportions* among columns rather than just the relation 'is taller than'. Similar refinements could be investigated in the musical case, but here we will be content to sketch the barest of semantics in order to provide a 'proof of concept', leaving such refinements for future research.

5.2 An example of musical truth

Because this is all rather abstract, we should start with a highly simplified example. Think again of the C – G – C progression we saw in Strauss's *Zarathustra*, where it was used to evoke a sunrise. We discussed at some length the role played by pitch height, but here we will focus on just two properties, one harmonic and one not. First, within this initial sequence, the key is C (major or minor – this is initially underspecified), and thus C is more stable than G; as a result, the progression is from the most stable position, to a less stable position, back to the most stable position. Second, the progression is realized with a crescendo.

In order to analyze progressions that just involve these two parameters, we will consider sequences of pairs of the form <note/chord, loudness>, as illustrated in (17). For the sake of generality we take the first members of the pairs to be chords, and we may assume general principles of relative stability of chords, notably the fact that I is more stable than V, which itself is more stable than IV (within the context of the beginning of Strauss's Zarathustra, one may think instead of different components of a I chord, with C more stable than G).

(17) a. M = <<I, 70db>, <V, 75db>, <I, 80db>>
b. M' = <<I, 70db> , <IV, 75db>, <V, 80db>>
c. M" = <<IV, 80db>, <V, 75db>, <I, 70db>>

So here M is a crescendo progression from I to V to I. M' follows the same crescendo pattern, but goes from I to IV to V; while M" is diminuendo from IV to V to I. For present purposes, a musical piece is just an ordered series of such pairs. The ones we just considered contained only 3 musical events each, but of course there could be more.

Now we will take each pair of the form <note/chord, loudness> to denote an event in the world. Our musical pieces M, M' and M" will thus each depict a series of 3 events in the world. But as we saw earlier, events are not enough: inferences are derived by considering virtual sources of the voices, and these sources are often identified with *objects in the world*. Accordingly, we associate:
(i) with any voice M an object O;
(ii) with the series of musical events $m_1, \ldots, m_n$ that make up M, a series of world events $e_1, \ldots, e_n$, with the requirement that each of these events should have O as a participant.

(18) Let M be a voice, with M = $<M_1, \ldots, M_n>$. A possible denotation for M is a pair $<O, <e_1, \ldots, e_n>>$ of an object and a series of n events, with the requirement that O be a participant in each of $e_1, \ldots, e_n$.

(See Wolff 2015 for a rather different event-based analysis of musical meaning, one without a notion of 'musical truth'.).

The next step is to determine under what conditions a series of musical events can be taken to be true of real world events – in other words, under what conditions the depiction is true. In our analysis, this will be the case when these real world events satisfy certain inferences triggered by the musical voice – inferences from normal auditory cognition, and tonal inferences. Here we will only give a 'toy example' of an analysis of this kind; the goal is merely to illustrate the conceptual points we are making, leaving it for future research to develop analyses that are more realistic and thus take into account more parameters as well as more preservation principles).

Starting from the pieces in (17) and the specification of possible denotations in (18), we will say that the music piece M = $<M_1, \ldots, M_n>$ is true of the pair of an object and events it undergoes, $<O, <e_1, \ldots, e_n>>$, just in case $<O, <e_1, \ldots, e_n>>$ is a possible denotation for M, and in addition the mapping from $<M_1, \ldots, M_n>$ to $<e_1, \ldots, e_n>$ preserves certain requirements, listed in (19).

(19) Defining 'true of'
Let M = $<M_1, \ldots, M_n>$ be a voice, and let $<O, <e_1, \ldots, e_n>>$ be a possible denotation for M. **M is true of $<O, <e_1, \ldots, e_n>>$** if it obeys the following requirements.

a. Time
The temporal ordering of $<M_1, \ldots, M_n>$ should be preserved, i.e. we should have $e_1 < \ldots < e_n$, where < is ordering in time.

b. Loudness
If M_i is less loud than M_k, then either:
(i) O has less energy in e_i than in e_k; or
(ii) O is further from the perceiver in e_i than in e_k.

c. Harmonic stability
If M_i is less harmonically stable than M_k, then O is in a less stable position in e_i than it is in e_k.

While the temporal condition does not need justification, the Loudness and Harmonic stability conditions do. Let us consider them in turn.

The preservation condition on Loudness is disjunctive. The intuition is that in auditory cognition in general, louder sounds are associated either with objects that have more energy, or with objects that are closer, as discussed in Section 3.3.

The preservation condition on Harmonic stability is purely musical, and captures the intuition that less stable events in musical space should denote less stable events in the world. The simplest example of this phenomenon was discussed in Section 4.1 in connection with Saint-Saëns's Tortoises, where a dissonance was rather clearly interpreted as the tortoises tripping.

Two essential remarks should be added. First, *none of the conditions in (19) requires that the denotations produce sound*. This is the sense in which our source-based semantics is abstract: the properties we attribute to the objects are ones that would be inferred about sound sources, but these properties themselves need not involve sound, and thus they may be true of objects that are not sound-producing. Second, a music piece will in general be true of lots and lots of objects and their associated events. The same situation arises in most semantic systems, such as human language: to understand the meaning of the sentence *It is raining* is to know in which kinds of situations it is true (see for instance Larson 1995 and Schlenker 2010 for handbook summaries of the analysis of meaning as truth conditions). But it is particularly striking that in music the denoted situations might be extremely heterogeneous, as we will see shortly. This is because the informational content of music is

underspecified and abstract, which has led some to think that music has no semantics at all. But an underspecified and abstract semantics is very different from no semantics at all.

We can now illustrate how these preservation conditions will lead to a notion of truth. We consider three objects: the sun, a boat, a car. And we will consider 'bare bones' versions of several sequences of events. For the sun, a sunrise and a sunset. For the boat, a movement towards the perceiver, and a movement away from it. For the car, just a car crash. We will analyze these events in a highly simplified fashion, with each event made of three sub-events. In this way, we will obtain five possible denotations for our piece M = <<I, 70db>, <V, 75db>, <I, 80db>> in (17)a.

(20) a. sun-rise = <sun, <minimal-luminosity, rising-luminosity, maximal-luminosity>>
b. sun-set = <sun, <maximal-luminosity, diminishing-luminosity, minimal-luminosity>>
c. boat-approaching = <boat, <maximal-distance, approach, minimal-distance>>
d. boat-departing = <boat, <maximal-distance, departure, maximal-distance>>
e. car-crash <car, <movement_1, movement_2, crash>>

Since M is comprised of three musical events, and each of the sequences in (20) is of the form <object, <event_1, event_2, event_3>>, each is a possible denotation for M according to (18). It remains to see whether M is true of any of these sequences. As we will argue, it should be true of sun-rise and boat-approaching but not of the other events because only sun-rise and boat-approaching involve sequences of events that preserve the key properties of M: the music goes from stable to less stable to more stable (I-V-I); and loudness increases, which can be interpreted as a rise in (real or perceived) level of energy, as in sun-rise, or as an objet approaching, as in boat-approaching.

Let us see in greater detail how this result can be derived. We rely on intuitive properties of the stability or level of energy of events in the world; in a more systematic analysis, some empirical or formal criterion should of course be given to assess 'stability' and 'level of energy' of real world events on independent grounds.

Let us first note that all the sequences of events given in (20) are intended to obey the time ordering condition stated in (19)a: in each sequence <object, event_1, event_2, event_3>, the events come in the order event_1 < event_2 < event_3. So for M to be true of one of the sequences in (20), all we need to check is that it satisfies the Loudness and the Harmonic Stability conditions.

• Consider first sun-rise in (20)a. Since M has a crescendo, M_1 is less loud than M_2, which is less loud than M_3. The Loudness condition in (19)b mandates that minimal-luminosity should have less energy or be further from the perceiver than rising luminosity; and similarly for rising-luminosity relative to maximal-luminosity. Certainly the perceived level of energy fits the bill (in physical terms, the interpretation in terms of rising proximity to the perceiver is astronomically correct, though in psychological terms the 'energy'-based interpretation seems more relevant). This shows that the Loudness condition is satisfied. Turning to the Harmonic Stability condition, it too would seem to be satisfied: the initial and final sub-events are relatively static, hence stable, whereas the intermediate event is dynamic, hence less stable. In sum, all conditions are satisfied to say that M is true of sun-rise.

• By contrast, we will now see that the same reasoning leads us to say that M is *not* true of sun-set in (20)b. The Harmonic Stability condition is not the issue: just as with sun-rise, the events that begin and end the process can be taken to be the most static and thus stable. On the other hand, the Loudness condition is not satisfied: when we consider the first and the second event, namely maximal-luminosity and diminishing-luminosity, there is neither an increase in 'energy' level, nor an approach.

• The argument is almost identical in (20)c-d as in (20)a-b (in particular with respect to the Harmonic Stability condition), but with one difference: since it does not make much sense to say that a boat approaching is gaining energy (if anything, it might slow down as it approaches the coast), the Loudness condition is satisfied in (20)c by an increasing proximity of the source to the perceiver (fulfilling (19)b(ii)) rather than by an increasing level of energy of the source (pertaining to (19)b(i)). The Loudness condition is violated in (20): its two initial sub-events are maximal-distance followed by departure, and the second does not have more energy than the first, nor is it closer than it – hence the crescendo character of M is not properly interpreted.

• Finally, the car-crash event in (20)e might or might not satisfy the Loudness condition, depending on whether we take the sequence <movement_1, movement_2, crash> to correspond to an increase in energy and/or to a movement towards the perceiver. But plausibly the Harmonic stability condition is not satisfied: one would expect that the musical event corresponding to the crash is the least stable of all three events, whereas here it corresponds to the final I of the piece. Things would be different if the piece finished in a highly dissonant chord, but this is not the case here.

In summary, the piece M introduced above is true of sun-rise and boat-approaching but not of the other events considered here; needless to say, neither the sun nor the boat need to produce sound in order to be denoted, which we take to be an appropriate result, and a benefit of the formal approach sketched here (without it, one might think that a source-based semantics can only posit sound-producing denotations, which would be undesirable). In the general case, a piece will likely be made true by extremely diverse situations, because our preservation conditions make reference to abstract properties (e.g. level of energy, stability) that could be instantiated in countless ways. This is as it should be: musical inferences are highly underspecified, and this property should be preserved by an adequate semantics. From the present perspective, to understand the meaning of a sequence of notes is to understand which possible denotations make it true (which does not entail fixating on any specific one of these denotations). This understanding may be sharpened by extrinsic considerations, such as titles in program music, or extra-musical considerations in dance and opera: these may be taken to reduce the set of possible denotations that make the music true. But as is the case for language, there will in general be a multiplicity of situations that make a piece true.

6 Musical Syntax and Event Mereology

Having argued that one can make sense of the referential content of music, we will now suggest that some aspects of musical syntax can be reinterpreted in semantic terms. Specifically, we will argue that the 'grouping structures' postulated by Lerdahl and Jackendoff 1983 derive from an attempt to organize the musical surface in a way that preserves the structure of the denoted events (we take this interpretation to be in the spirit of Lerdahl and Jackendoff, who emphasize that grouping principles come from perception, not 'syntax'). In particular, we will propose that a musical group A is taken to belong to a musical group B if, on any true interpretation, the real world event denoted by A can naturally be taken to be a sub-event of that denoted by B. In other words, grouping structure will be taken to reflect the 'part-of' relations among the denoted events, what is called 'mereology' (or sometimes 'partology') in semantics. We will speculate that this semantic approach might even extend to Lerdahl and Jackendoff's 'time span structures'.

Two clarifications will be useful at the outset. First, we emphasized in Section 5 that our analysis is appropriately abstract: although the properties assigned to possible denotations are ones that would be inferred about sound sources, these properties themselves need not involve sound, and thus they may be true of objects that are not sound-producing. Still, the principles by which we structure the music may stem from general principles that allow auditory stimuli to be sequenced so as to correspond to the structure of the events that caused them. The situation is in this respect reminiscent of visual diagrams used to represent non-visual stimuli. For instance, although the graph in (2)c represents sound (specifically, loudness) rather than visually perceptible objects, we naturally sequence it using general principles of visual perception *as if* we were trying to uncover the structure of objects that caused this visual stimulus. Second, the analysis we are about to develop takes the tree-like structure of musical syntax *not* to be of the same nature as that found in linguistic syntax. Conceptually, tree-structure in linguistic syntax is taken to reflect the way in which words are put together, what is sometimes called their 'derivational history'; by contrast, we take the musical syntax under consideration here to stem from the fact that *auditory stimuli usually reflect the structure of events that caused them*. Technically, following Lerdahl and Jackendoff 1983 we will take the tree structures obtained in this musical syntax to be less constrained than standard 'derivation trees' in linguistic syntax.

6.1 Levels of musical structure

Lerdahl and Jackendoff posit four levels of structure, summarized as follows in Lerdahl 2001:

> GTTM proposes four types of hierarchical structure simultaneously associated with a musical surface. Grouping structure describes the listener's segmentation of the music into units such as motives, phrases, and sections. Metrical structure assigns a hierarchy of strong and weak beats. Time-span reduction, the primary link between rhythm and pitch, establishes the relative structural importance of events within the rhythmic units of a piece. Prolongational reduction develops a second hierarchy of events in terms of perceived patterns of tension and relaxation.

Some of Lerdahl and Jackendoff's structures have been analyzed in terms of a generative syntax, as in Pesetsky and Katz 2009 for prolongational reductions. By contrast, we will be solely concerned with grouping structure and time-span reductions. Lerdahl and Jackendoff's own discussion departs in two respects from a 'generative syntax' analysis.
(i) First, they take their structures to be based on parsing rather than generation, and to rely heavily on preference principles rather than on categorical principles of well-formedness.

(ii) Second, Lerdahl and Jackendoff take some of their own structures to be based in perception and to follow from very general Gestalt principles.
(i) may or may not be essential, for one might present the same system in terms of parsing or generation, as Pesetsky and Katz 2009 argue. But (ii) is essential for present purposes, as it suggests that *the rules that provide structure to musical form are rules of perception designed to capture the structure of the represented events*.

6.2 Grouping structure and event mereology

Grouping structures, as we will now argue, are best seen as originating in the mereological structure of events, i.e. the part-of structure (sometimes called 'partology') of events. More specifically, we take Grouping structure to derive from the fact that the auditory traces of (real word) events are organized in a way that reflects the structure of these events. In some cases this gives rise to a tree-like structure, but for reasons that are very different from what we find in human language.

We will proceed in three steps. First, we will note that it is uncontroversial that events come with a part-of structure (large events are made of smaller events), and that with additional assumptions a tree-like structure is obtained. Second, we will argue that the result is a more flexible theory of music structure than a syntactic tree structure would yield, in particular because in some cases it allows for overlap among groups. Third, we will refer to literature on event perception to suggests that events are indeed perceived as structured.

6.2.1 Event mereology and tree structures

Events are standardly analyzed as having a part-of structure, with large events being made of smaller events (e.g. Varzi 2015). Still, the part-of structure is very weak, and thus further assumptions are needed to obtain tree-like structures.

We will start from the simple part-of structure given in (21); it has in particular the consequence that if an event e has parts, then *their* parts are also parts of e (Transitivity).

(21) Part-of structure in mereology (e.g. Varzi 2015)
The part-of relation P is defined by the following requirements, where *Pxy* is read as: 'x is a part of y':
a. Reflexivity: For all x, Pxx
b. Transitivity : For all x, y, if Pxy and Pyz, then Pxz
c. Antisymmetry: For all x, y, if Pxy and Pyx, x = y

The notion of 'proper part' follows from that of a 'part': x is a proper part of y if and only if (henceforth: iff) x is a part of y and x and y are not identical. For simplicity, we will further assume that every event is made of atomic events, i.e. events that do not themselves have proper parts, as defined in (22).

(22) Atoms (e.g. Varzi 2015)
a. Definition: x is an atom iff x has no proper part.
b. Atomicity: For all x, x has a part which is an atom

(23) Assumption: every event is made of atomic events.

Assuming that this structure applies to events, we can define a partially ordered structure in which an element immediately dominates its immediate proper parts, and restrict attention to graphs that lead to atoms. Among all the structures of this sort, we will obtain tree structures as special cases – but further assumptions are needed to get there.

First, it makes sense to assume that atomic events are ordered in time, as stated in (24).

(24) If x and y are atomic events, either x < y or y < x, where < is a temporal ordering.

We henceforth use the list of its atoms to name an event, omitting 'trivial' decompositions, namely those that involve events with just two atomic parts (since these can be decomposed in just one way). For an event with atomic sub-events a, b, c, this leads to the possible decompositions in (25).

(25) Possible decompositions of abc - simplified notation
a. abc –> a, b, c

b. abc –> ab, c

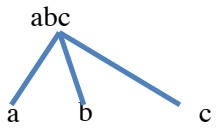
c. abc –> a, bc

d. abc –> **ac**, b

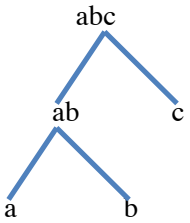
e. abc –> **ab, bc**

Now it can immediately be seen that (25)a,b,c correspond to 'standard' 'syntactic' trees that could be obtained from a context-free grammar, as illustrated in (26)a,b, c. But (25)d,e require 'trees' with an unusual shape, as illustrated (26)d,e.

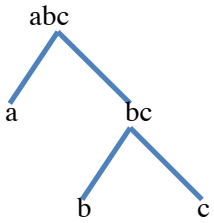
(26) a.



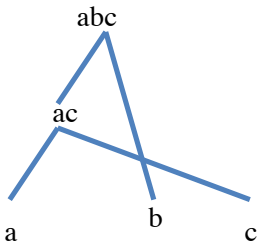
b.



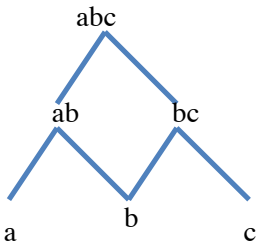
c.



d.



e.



The situation in (26)d violates the assumption that 'constituents are not discontinuous' (a standard but not universal assumption in linguistics, see e.g. McCawley 1982 for exceptions). In standard syntax, it is normally prohibited by the assumption that in a context-free rule of the form M –> $D_1 \ldots D_n$, the output elements $D_1 \ldots D_n$ are temporally ordered with $D_1 < \ldots < D_n$, with a requirement that if $D_i < D_k$, then all the terminal nodes dominated by D_i precede all the terminal nodes dominated by D_k (see Kracht 2003 p. 46); precisely this condition fails in (26)d, as we can neither have ac < b nor b < ac.

The situation in (26)e violates the assumption that a terminal node is the output of a single context-free rule, so that 'multi-dominance' is prohibited (this prohibition was reconsidered in syntax in theories of 'multidominance' (e.g. de Vries 2013)).

Can these structures be blocked in a natural way if we take them to reflect event structure? We believe that they can be.

Consider first (26)e. It is an uneconomical event decomposition, because we could remove a branch above b (thus attributing b exclusively to the left-hand or to the right-hand node that dominates it) without affecting the set of atomic elements that constitute the whole. This condition of economy can be enforced by (27), which prohibits overlap among events unless one is contained within the other.

(27) Minimal part-of structures
A part-of structure is minimal if whenever x is part of y and x is part of z, y is part of z or z is part of y.

This condition is of course violated by (26)e: b is part of ab and of bc, but neither is part of the other.

We take this minimality condition to be a principle of optimal event perception, but one that should have exceptions. These could be of two sorts:
(i) overlap: cases in which there is a reason to think that the represented (real world) events are best decomposed in a non-economical fashion, with a part which is common to both (for instance because there is a smooth transition between two events [this might be relevant for modulations]);
(ii) occlusion: cases in which there is a reason to think that two distinct events share the same auditory trace.
We come back in Section 6.2.2 to exceptions of both sorts.

Consider now (26)d. It leads one to posit that an event has a discontinuous auditory trace. Two assumptions are needed to prohibit this case.

The first assumption, which makes much intuitive sense, is that real-world events are normally connected. But this measure is not enough. Consider an analogous case in the visual domain. It makes sense to posit that both objects and events satisfy a condition of spatial or temporal connectedness. Still, due to occlusion, there are numerous objects and events that we *see* as disconnected, even when our cognitive system is able to take occlusion into account and to posit a single underlying object or event despite the disconnected nature of the percept.

Thus in order to prohibit structures such as (26)d we must also posit that cases of auditory occlusion do not occur. This makes much sense in some standard situations: if you are in the middle of a conversation while a car passes by, it will rarely happen than the background noise is so strong as to occlude the conversation, or conversely.

In this case as well, we predict that there should be exceptions, of two types.
(i') There could be cases in which it makes sense to assume that the connectedness condition fails to apply to real-world events.
(ii') There could also be cases in which the connectedness condition does apply to real world events, but not to their auditory traces, in particular due to cases of occlusion.

6.2.2 Exceptions

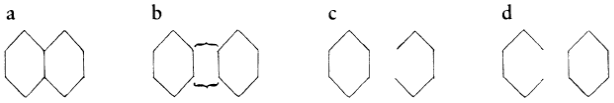
Lerdahl and Jackendoff 1983 emphasize that cases such as (26)e arise in music. Since they take grouping structure to result from principles of perception rather than from syntactic rules, they do not take these 'exceptions' to refute their account. On the contrary, they explain these exceptions by appealing to analogous cases in visual perception. Furthermore, the exceptions they list are of the two types we announced above: in case of overlap, the denoted events are construed as sharing a part; in cases of occlusion, the auditory trace of an event occludes that of another event.

- *Overlap*

Lerdahl and Jackendoff 1983 illustrate visual overlap by the case in which a single line serves as the boundary between two objects, and is thus best seen as belonging to both, as in (28)a, which is preferably analyzed as (28)b rather than as (28)c-d. In our terms, this is a case in which the optimal mereological decomposition of the underlying object should not be minimal – although an alternative possibility is that we are dealing with two different lines that have a unique visual trace.

(28) Lerdahl and Jackendoff's visual analogue of overlap (Lerdahl and Jackendoff 1983 p. 59)

3.29

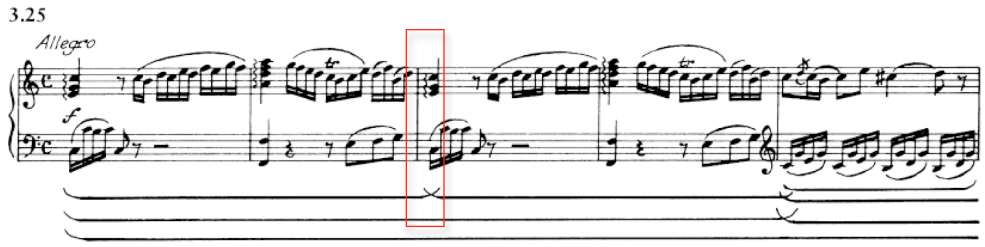


Cases of overlap are probably pervasive in event decomposition as well. A person's walk is a succession of cycles in which a foot touches ground, goes up, and touches ground again. Each subevent in which the foot touches ground is both the completion of a cycle and the beginning of the next one – an event counterpart of the objection perception case in (28).

Lerdahl and Jackendoff 1983 cite the very beginning of Mozart's K. 279 sonata as an example of auditory overlap, as seen in (29). The I chord at the beginning of bar 3 seems to both conclude the first group and initiate the second, hence it can be taken as the trace of an event that plays a dual role as the end of one event and at the beginning of another. Alternatively, and less plausibly perhaps, this could be a case in which two distinct events have the same auditory trace (this is precisely the uncertainty we had in our discussion of the visual example in (28)).

(29) An example of overlap: the beginning of Mozart's K. 279 sonata (Lerdahl and Jackendoff 1983 p. 56; sound example **S29**)
https://www.youtube.com/watch?v=d26zRUWKc08 https://soundcloud.com/philippeschlenker/mozart-sonata-k279-beginning

3.25

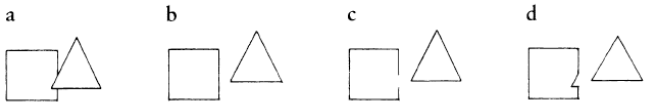


- *Occlusion*

The second case involves part of an object occluding another object, as in (30). Here the most natural interpretation of (30)a is as (30)b, which involves occlusion, rather than as (30)c-d, which do not.

(30) Lerdahl and Jackendoff's visual analogue of elision (Lerdahl and Jackendoff p. 59)

3.30

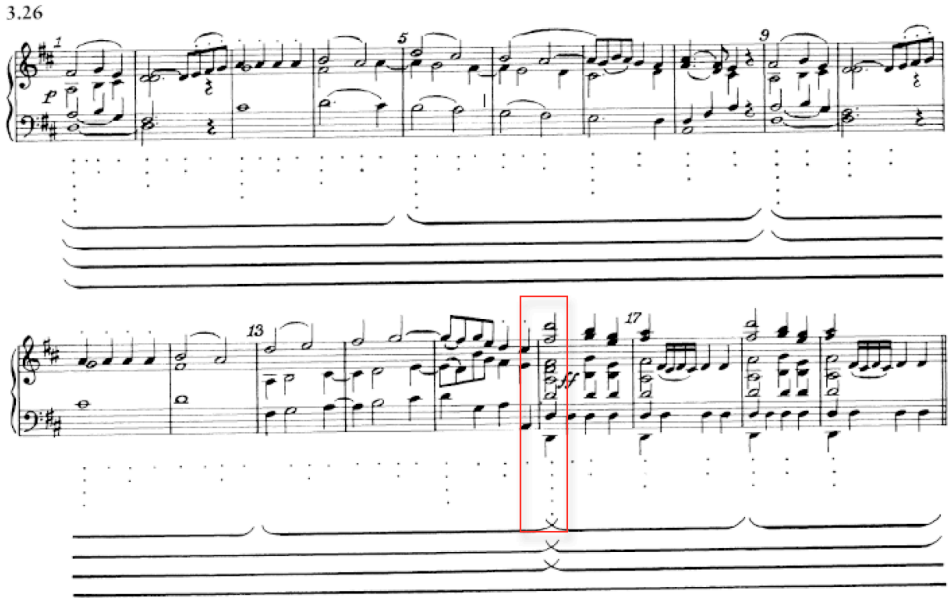


Here too, an event counterpart of object occlusion is not hard to find: a train passing by will visually, and sometimes auditorily, occlude numerous other events.

In music, this case is illustrated by what Lerdahl and Jackendoff call 'elision'. Their description (as well as the visual analogy they draw) makes clear that these are really cases of auditory occlusion, as in their discussion of the beginning of the allegro of Haydn's Symphony 104. As they write:

One's sense is not that the downbeat of measure 16 is shared (...) ; a more accurate description of the intuition is that the last event [of the first group] is elided by the fortissimo.

(31) An example of elision: the beginning of the allegro of the First movement of Haydn's Symphony 104 (Lerdahl and Jackendoff 1983 p. 57; sound example **S31**)
https://www.youtube.com/watch?v=OitPLIowJ70&t=2m14s https://soundcloud.com/philippeschlenker/mozart-sonata-k279-beginning



In sum, in several cases grouping structure departs from a simple tree structure, in ways that can be explained if musical groups are perceived as the auditory traces of events, whose mereological structure is reflected on the musical surface. In particular, there are cases of overlap in which a part is best seen as belonging to two events, and cases of occlusion in which the auditory trace of one event occludes that of another event.

6.2.3 Sequencing events

For our analysis to be plausible, one would need to establish that *independently from music* (or language, for that matter), events are naturally perceived with a part-of structure. Jackendoff 2009 argues that there are tree-like structures outside of language, and he gives the example of actions, which may be structured in various ways without thereby having a linguistic representation. In the experimental literature, Zacks et al. 2001 provide evidence that subjects sequence events (presented by way of videos) in a hierarchical fashion. And work by Neil Cohn (e.g. Cohn et al. 2014) suggests that visual narratives (comics) have a hierarchical structure as well. In the future, it would be particularly interesting for music semantics to investigate cases in which two events may overlap, something which is crucial to our understanding of Lerdahl and Jackendoff's cases of grouping overlap.

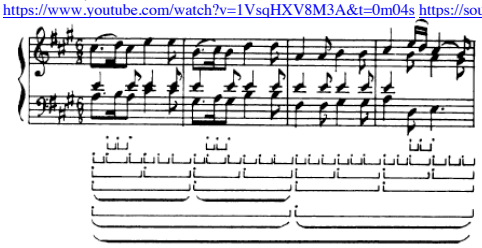
6.3 Time-span reductions and headed events

It is uncontroversial that Western classical music has a metrical structure that yields an alternation of strong and weak beats. Lerdahl and Jackendoff 1983 analyze it with rules that are very similar to those used in metrical phonology. They take metrical structure to be essential to the organization of events at micro-levels. At larger levels, they take them to be organized by grouping structure. But Lerdahl and Jackendoff argue that the structures obtained are still insufficient in that they fail to distinguish different levels of importance within musical groups. Formally, they propose that their tree structures should be seen *headed*: in each natural unit, one musical event is more important than

the others and thus counts as its 'head'. In a nutshell, heads are events that are rhythmically more prominent and/or harmonically more stable. In Lerdahl and Jackendoff's words,

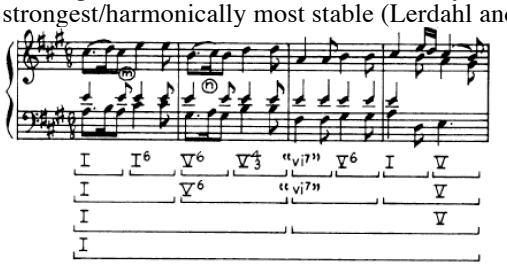
> at the most local levels, the metrical component marks off the music into beats of equal time-spans; at larger levels, the grouping component divides the piece into motives, subphrase groups, phrases, periods, theme groups, and sections. Thus it becomes possible to convert a combined metrical and grouping analysis into a time-span segmentation, as diagrammed for the beginning of [Mozart's] K. 331 in 5.11. (p. 119)

(32) Metrical structure [segments] and grouping structure [brackets] for the beginning of Mozart's K. 331 piano sonata (Lerdahl and Jackendoff 1983; sound example **S32**)
https://www.youtube.com/watch?v=1VsqHXV8M3A&t=0m04s https://soundcloud.com/philippeschlenker/mozart-sonata-k331-beginning



The next step in the construction of time-span segmentation is the selection of a head in each group, as is illustrated in (33).

(33) Time-span reduction obtained from (32) by selecting in each the musical event which is metrically strongest/harmonically most stable (Lerdahl and Jackendoff 1983)



As Lerdahl and Jackendoff write (p. 120), "in the span covering measure 2, the V^6 is chosen over the V^4_3, and proceeds for consideration in the span covering measures 1-2.; here it is less stable than the opening I, so it does not proceed to the next larger span; and so forth. As a result of this procedure, a particular time-span level produces a particular reductional level [the sequence of heads of the tirne-spans at that level)."

It remains to ask whether the headed nature of time-spans should be taken as primitive, or might follow instead from a more general strategy of event perception. Jackendoff 2009 argues that there are headed structures outside of music and language, in particular in the domain of complex action. From the present perspective, however, a natural question is whether we could explain the headed nature of time spans as reflecting the headed nature of the denoted events. We conjecture that this is indeed the case, and specifically (i) that real world events are often perceived not just as structured but also as headed, and (ii) that considerations of energy (comparable to rhythmic strength) and of stability (comparable to harmonic stability) both play a role in selecting the head of an event.

While this is pure speculation at this point, we would like to discuss one suggestive example. Consider a simplified dynamic representation of a person walking, as in (34). We submit that if one were to sequence the walk into events and sub-events, one would find that moments at which the foot touches the ground delimit events, but in addition that these are the most important sub-events in each cycle – the 'head' of the relevant event, in terms of the present discussion. These are clearly points at which impulses of energy are given, somehow like points of metrical strength in music, and probably also points of greatest physically stability.

(34) Person walking
https://www.youtube.com/watch?v=ZPI7_oVNB24

7 Emotional Effects in Music

Much theoretical and experimental work on musical meaning focuses on emotions – which have largely been absent from our discussions (see also Maus 1988 for an account of music semantics in which actions rather than emotions are primitive). Do they have a natural place in our source-based analysis? In fact, they have several. First, emotions can be attributed to animate sources – which may lead to emotions in the listener by a process of 'emotional contagion'. Second, we will describe a further mechanism by which sources are construed as *experienced* by the listener, which may account for particularly powerful effects in music. (In addition, since music is endowed with a semantics, it can be viewed as a *discourse* emanating from an intentional agent – the narrator and/or the musician. And of course emotions may be attributed to that agent as well. We disregard this point for the sake of simplicity.)

We should set aside at the outset effects that stem from the ability of sound to cause emotions irrespective of its semantics. An extremely loud sound may cause fear. Arnal et al. 2015 show that an acoustic property of human screams called 'roughness' (corresponding to amplitude modulations ranging from 30 to 150 Hz) specifically targets subcortical brain areas involved in danger processing – and of course does so irrespective of any semantics. Somewhat closer to our topic, Bonin et al. 2016 state a 'source dilemma' hypothesis according to which "uncertainty in the number, identity or location of sound objects elicits unpleasant emotions by presenting the auditory system with an incoherent percept" – and they show experimentally that subjects rate "congruent auditory scene cues as more pleasant than melodies with incongruent auditory scene cues." Here it is not so much the inferences about sources that yield emotions as the *difficulty* of identifying the sources. From a broader theoretical perspective, Huron 2006 argues that various emotions of a musical or extra-musical nature derive from general properties of expectation, i.e. of our attempts to anticipate what will come next, in music or elsewhere. For Huron, "the emotions evoked by expectation involve five functionally distinct physiological systems: imagination, tension, prediction, reaction, and appraisal" (p. 7), hence an 'ITPRA' theory (whose name derives from the initials of these five systems) that seeks in particular to derive musical emotions from the interaction of these systems with musical anticipations. Importantly for our purposes, Huron's analysis need not depend on the existence of a music semantics. We focus the rest of this discussion on those emotion attributions that interact with our semantics.

7.1 Emotions attributed to the sources

To motivate our source-based semantics, we cited above Lerdahl's (2001) analogy between music and Heider and Simmel's (1944) abstract animations, with musical events behaving "like interacting agents that move and swerve in time and space, attracting and repelling, tensing and coming to rest". While virtual sources need not be interpreted as animate, when they are their behavior may also be indicative of emotions. As is the case more generally, inferences may be drawn on the basis both of normal auditory cognition and of the interaction between the sources and tonal pitch space (numerous tonal and non-tonal means of conveying musical emotions are surveyed in Gabrielsson and Lindström 2010, who provide a summary of experimental studies).

Inferences from normal auditory cognition have been explored in detail in the recent experimental literature, with imitations of animal signals and of human speech as primary mechanisms of inference. As mentioned above, Blumstein et al. 2012 argue that adding distortion noise (nonlinearities) in a music piece induce in listeners an effect of "increased arousal (i.e. perceived emotional stimulation) and negative valence (i.e. perceived degree of negativity or sadness)", and they argue that such "harsh, nonlinear vocalizations" are produced by many vertebrates when alarmed, possibly because they "are produced when acoustic production systems (vocal cords and syrinxes) are overblown in stressful, dangerous situations". As was also mentioned, Bowling et al. 2010 seek to find correlates of major vs. minor intervals in excited vs. subdued speech, which might explain some of the emotional associations with these intervals. Bowling et al. 2012 further show that interval size is correlated with affect in language and in music: "in both Tamil and English speech negative/subdued affect is characterized by relatively small prosodic intervals, whereas positive/excited affect is characterized by relatively large prosodic intervals"; similarly, in both Carnatic and Western music melodic intervals "are generally larger in melodies associated with positive/excited emotion, and smaller in melodies associated with negative/subdued emotion".

More generally, Juslin and Laukka 2003 propose a theory in which "music performers are able to communicate basic emotions to listeners by using a nonverbal code that derives from vocal expression of emotion". In a review of multiple studies, they argue that similar cues are used in the vocal and in the musical domain to express a variety of emotions, as summarized in (35) (F0 = fundamental frequency). The parallelism between the vocal and the musical domain is expected from the perspective of a source-based semantics in which inferences about the emotional state of a source (or for that matter of a musical narrator) are drawn in part on the basis of normal auditory cognition.

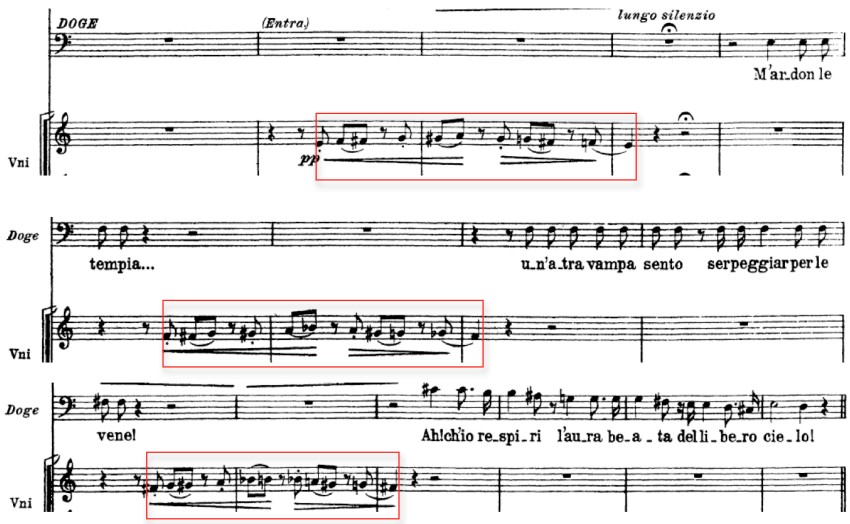
(35) Juslin and Laukka 2003: Summary of Cross-Modal Patterns of Acoustic Cues for Discrete Emotions

Emotion	Acoustic cues (vocal expression/music performance)
Anger	Fast speech rate/tempo, high voice intensity/sound level, much voice intensity/sound level variability, much high-frequency energy, high F0/pitch level, much F0 pitch variability, rising F0/pitch contour, fast voice onsets/tone attacks, and microstructural irregularity
Fear	Fast speech rate/tempo, low voice intensity/sound level (except in panic fear), much voice intensity/sound level variability, little high-frequency energy, high F0/pitch level, little F0/pitch variability, rising F0/pitch contour, and a lot of microstructural irregularity
Happiness	Fast speech rate/tempo, medium-high voice intensity/sound level, medium high-frequency energy, high F0/pitch level, much F0/pitch variability, rising F0/pitch contour, fast voice onsets/tone attacks, and very little microstructural regularity
Sadness	Slow speech rate/tempo, low voice intensity/sound level, little voice intensity /sound level variability, little high-frequency energy, low F0/pitch level, little F0/pitch variability, falling F0/pitch contour, slow voice onsets/tone attacks, and microstructural irregularity
Tenderness	Slow speech rate/tempo, low voice intensity/sound level, little voice intensity/sound level variability, little high-frequency energy, low F0/pitch level, little F0/pitch variability, falling F0/pitch contours, slow voice onsets/tone attacks, and microstructural regularity

In addition, Sievers et al. 2013 posit homologies between the mechanisms that trigger emotions in music and in the movement of a ball that can take various shapes. Specifically, they show experimentally that features that can plausibly be matched across domains (rate, jitter, i.e. regularity of rate, direction, step size, and dissonance/visual spikiness) give rise to similar emotions with music and with movement, and moreover that the finding holds across very different cultures.

To make concrete the emotional import of inferences from normal auditory cognition, let us consider a striking passage at the end (Act III, Scene 3) of Verdi's *Simon Boccanegra*: three chromatic cycles evoke rising and receding effects of the poison that Simon drank in Act II. Each of the boxed sequences in (36) is made of 2 ascending chromatic sequences in eighth notes (e.g. E F F#; G G# A), followed by one descending sequence with a similar rhythm (e.g. G# G F#), and a 2-note sequence (e.g. F E) ending on a longer note – the very same one that had started the cycle. The following cycles follow the same pattern, raised each time by a half-tone. The effect produced is arguably to evoke three cycles of Simon's increasing discomfort, by way of a mapping between the musical source and the intensity of Simon's discomfort: loudness and melodic height are both indicative of the strength of the discomfort.

(36) Verdi - Simon Boccanegra, Act III, Scene 3 (partial score: Simon and violins; sound example **S36**)
https://youtu.be/8F9Otx-wee8 https://youtu.be/92I6KqBegRQ
'My head is burning, I feel a dreadful fire creeping through my veins...'



Still, the reason these sequences can be interpreted in terms of *discomfort* (or worse) is probably due in part to the chromatic nature of the sequences. This can be seen by comparing the original, chromatic version (sound example **S36.1**) [https://soundcloud.com/philippeschlenker/verdi-boccanegra-poison-effect-base] with one rewritten in minor mode (sound example **S36.2**) [https://soundcloud.com/philippeschlenker/verdi-boccanegra-poison-effect-minor] or in major mode (sound example **S36.3**) [https://soundcloud.com/philippeschlenker/verdi-boccanegra-poison-effect-major]: certainly the first version is more appropriate to evoke a discomfort that the latter two. This highlights the importance

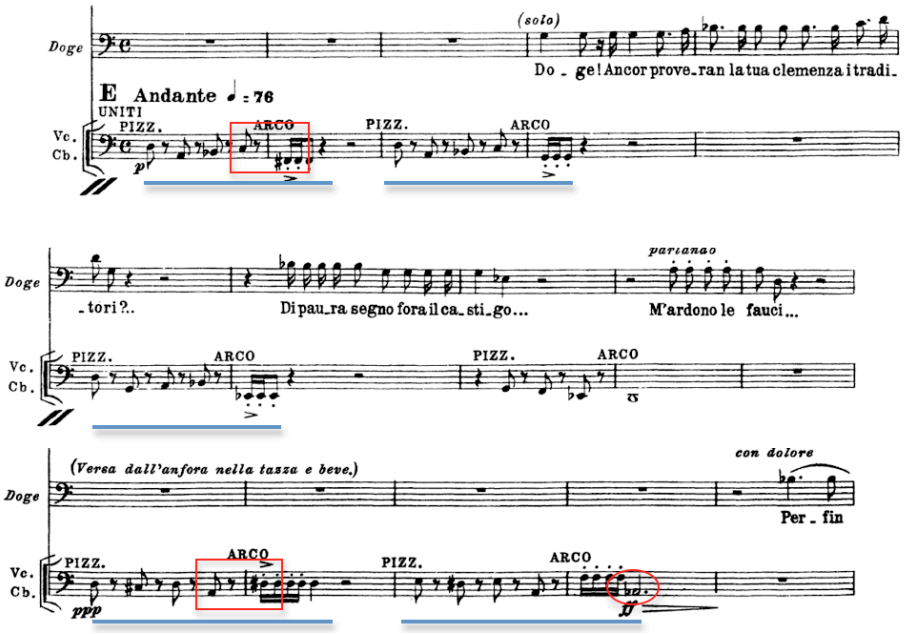
of specifically tonal inferences on emotions. Gabrielsson and Lindström 2010 review a rich literature that suggests that dissonances are interpreted in terms of unpleasantness, tension and fear, among others – which is relevant to the effect produced by the chromatic series in (36). And they also survey evidence for the traditional correlation between major mode and happiness on the one hand, and minor mode and sadness on the other. Unsurprisingly from this perspective, if the original version of Mahler's Frère Jacques (sound example **S36.4**) [https://soundcloud.com/philippeschlenker/mahler1-3ext-orchestra-beginning-normal] is rewritten in major mode (sound example **S36.5**) [https://soundcloud.com/philippeschlenker/mahler1-3ext-orchestra-beginning-normal-major], its appropriateness for a funeral march becomes quite a bit less convincing.

7.2 External vs. internal sources: a refinement

The preceding section provided the simplest mechanism of emotion attribution within our source-based system – accounting for some instances of what is called 'perceived'/'expressed' (as opposed to 'felt') emotion in the literature (see Gabrielsson 2002 for a discussion of the possible relations between perceived and felt emotion, and Evans and Schubert 2002 for relevant experimental data). But we believe a refinement of the analysis can explain why music can trigger emotions that seem to come from the listener herself (this is in addition to the case of emotional contagion, whereby the listener feels an emotion by virtue of assigning it to an external, animate source). Since our analysis leaves entirely open what the sources of the music are conceived to be, we can treat some of them as *experienced* sources. In other words, it makes much sense to take the objects and events that our analysis posits to be *experienced* objects and events rather than purely external ones. In this way, voices may be associated with series of experienced events, which may be partly or entirely internal. The existence of the tactus probably favors such 'internal' interpretations of the music: assuming that it is interpreted in terms of regular impulses of energy, it corresponds to a standard part of internal experience, involving for instance breathing, heartbeats, or just walking.

An example from Verdi's *Simon Boccanegra* will make this point concrete. In Act II, Scene 8, Simon drinks a cup which, unbeknownst to him, has been filled with poisoned water; consequences in Act III were discussed above in (36), when Simon begins to feel the effects of the poison. Even *before* he drinks from the cup, the cello theme makes clear that something momentous and disturbing is happening, as seen in (37). Crucially, the only character present, Simon himself, is unaware of what is going on, hence the music cannot serve to evoke his own emotions. Rather, it is probably the viewer's own emotions which are now reflected in the music (and possibly also the forces of destiny).

(37) Verdi's Simon Boccanegra, Act II, Scene 8 (sound example **S37**)
https://youtu.be/LIHh1QrM34I https://youtu.be/P9GZtLWvFmw

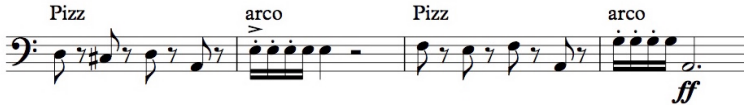


Several means conspire in the cello theme (underlined five times) to yield the impression that something momentous and disturbing is happening. The entire passage is in minor keys (arguably G minor in the first two lines and D minor in the last line). In addition, there in an alternation between slow eighth notes, with pizzicato timbre, and fast sixteenth notes, arco, played with an initial accent: this evokes ordinary and light events followed by faster and heavier events combined with an impulse of energy. In the two boxed passages, the interval separating the slow eighth notes from the fast sixteenth notes is a tritone (diminished fifth), which is rather dissonant. And the last line involves a

gradual chromatic ascent, D D# E F, indicative of the dramatic development. Rewriting the last line in D minor without chromatic excursions (as in (38)b) suppresses the tritone interval, and removes much of the feeling of tension and anguish. Last but not least, the last five notes would lead one to expect a series FFFF F, but the fortissimo conclusion on a low Ab (circled) instead of an F indicates that the expected course of events has been disrupted. (In the version of La Fenice/RAI 2014, Simone Piazzola as Simon drinks from the cup at exactly that point [sound example **S37**].)

(38) a. The last line of (37) is written with a chromatic ascent and a tritone interval (boxed), yielding a feeling of tension and anguish (sound example **S38.a**)
https://soundcloud.com/philippeschlenker/verdi-boccanegrabase-poison

b. Rewriting a. in D minor (without chromatic excursions) removes much of the feeling of tension and anguish (re-written by A. Bonetto; sound example **S38.b**)
https://soundcloud.com/philippeschlenker/verdi-boccanegrav1-poison-d-minor



In such cases, our general framework could be applied, but only if we take the basic elements of our ontology to be experienced rather than objective elements – experienced in particular by the listener. How can this provision be incorporated into the formal analysis we sketched above? If we go back to our toy model in (19), we could for instance state the Harmonic stability condition in a slightly more sophisticated fashion. Considering a voice associated with an object O, we assumed that when a musical event M_i is less harmonically stable than M_k, O is in a less stable position in the event e_i denoted by M than in the event e_k denoted by M_k, as was stated in (19)b. We could now specify that in this case either O is in a less stable position in e_i than in e_k, or O's being in e_i causes a less stable emotion than O's being in e_k; as was the case for our talk of 'stability' of an event, the notion of a 'stable emotion' would need to be explicated in future research. Thus the modified Harmonic stability condition, stated in (39) is disjunctive, a property it shares with our old Loudness condition, seen in (19)a.

(39) Harmonic stability – Modified version
If M_i is less harmonically stable than M_k, then either:
(i) O is in a less stable position in e_i than it is in e_k; or
(ii) O's being in e_i causes a less stable emotion in the perceiver than O's being in e_k.

Let us add that we were forced to stipulate certain properties of stability of real world events in our initial examples illustrating Harmonic stability. While simple cases may be intuitive enough, one would need to develop an independent theory of the 'stability' of real world events. When we make provisions for the possibility that musical voices denote series of experienced events that may be associated with all kinds of emotions, it becomes clear that a proper music semantics presupposes an understanding of the structure of these emotions – a non-trivial requirement.

This brief discussion of the ways in which our semantics could make provisions for experienced events is only a proof of concept. But it suggests that that there are at least two ways in which a source-based semantics can incorporate the role of musical emotions: by way of emotions attributed to the sources; and by way of an extension of the framework in which some or all sources are construed in terms of experienced rather than purely external events.

8 Conclusions

8.1 Theoretical conclusions

If our proposal is on the right track, music has a semantics, although one which is based on very different principles from linguistic semantics. We have treated music cognition as being continuous with normal auditory cognition, and in both cases we took the semantic content of an auditory percept to be closely connected with the set of inferences it licenses on its virtual causal sources, analyzed in appropriately abstract ways (e.g. as 'voices' in some Western music). However, music semantics is special in that it aggregates inferences from two main sources: normal auditory cognition, but also tonal properties of the music. These two types of inference must be aggregated in a proper music semantics. We sketched a truth-conditional one, in which a music piece *m* is true of a series of events (undergone by an object) just in case there is a certain structure-preserving map between the musical events and the real world events they are supposed to denote.

We further argued that aspects of musical syntax can be reconstructed on semantic grounds. In particular, grouping structure can be seen to reflect the mereology (partology) of the denoted events, and we tentatively suggested that even the headed nature of Lerdahl's and Jackendoff's time-

span reductions could be reinterpreted in semantic terms. Finally, although music semantics is not specifically stated in terms of emotions, it has a natural place for them: emotions may be attributed to musical sources, and when these are construed as experienced rather than purely external objects, music may even appear to reflect the listener's emotions.

8.2 Methodological conclusions

Although we based our theoretical discussion on informal introspective judgments (which should be subjected to experimental methods in the future), we made frequent use of 'minimal pairs' to display semantic effects – a standard approach in experimental approaches, but possibly one that should be used more systematically when studying the effects of 'real' music.

In order to *explain* semantic effects, methods differ depending on whether they have their origin in normal auditory cognition or in properties of tonal pitch space. In the first case, similar effects must be displayed in non-musical audition (and more broadly in perception). In the second case, explanations have to be more theory-internal, building on what one takes to be relevant properties of tonal pitch space. Importantly, the inferences that one might need to test are quite abstract in nature, hence in future studies great care should be devoted to the precise formulation of the inferential questions, and further methods should be developed to sharpen semantic intuitions – for instance by providing additional information (by way of titles, stories, or other non-musical information) so as to make inferences more precise.

8.3 Further questions

Several important questions are left for future research.

(i) Since we only attempted to provide a 'proof of concept', we sketched the barest of music semantics. Real applications would of course require a more sophisticated analysis, but also a determination of the fine-grainedness of the semantics under study. As a point of comparison, on a very coarse-grained picture semantics, a hexagon may count as a map of France, but this would not be the case on a more-grained semantics; similar issues of fine-grainedness will arise in music semantics.

(ii) As noted by a reviewer, rhythm gives rise to inferences that are not necessarily derived from normal auditory cognition, since properties of musical rhythm differ sharply from properties of ordinary events. It might be that rhythmic inferences will have to be treated in part like tonal inferences, which are drawn on the basis of the interaction between musical sources and specifically musical constraints.

(ii) We have been silent about music *pragmatics*, the set of non-semantic inferences drawn by reasoning on the motives of the intentional subject that produces a message, be it linguistic or musical. In Schlenker 2016, we argue that some pragmatic effects, pertaining to information packaging, may arise in the absence of a semantics, while others might interact in interesting ways with the present account.

(iii) Once a music semantics and pragmatics are defined, there will be various levels at which intentions can be attributed – as was also the case of emotions in Section 7. First, some sources may be viewed as intentional. Second, musical units – e.g. phrases – are endowed with a semantics, and can be ascribed to an intentional agent that narrates the relevant scenes. Third, in complex cases there may be several such narrators, for instance in dialogical situations in chamber music – in which case the composer will not be identified to a single voice but to the 'playwright' who organizes them all. Fourth, the musicians lend their voices to the narrator (as actors do in theater) to realize the composer's intentions – but they may superimpose their own intentions as they do so. See Schlenker 2016 for brief remarks on this topic, and Monahan 2013 for a different typology.

(iv) As things stand, our account has nothing to say about aspects of musical syntax that are not captured by grouping structure and time-span reductions. In particular, we leave for future research a potential semantic study of Lerdahl and Jackendoff's (1983) 'prolongational reductions', which play a central role in Pesetsky and Katz's analysis (2009) of music syntax.

(v) Koelsch at al. 2004 argue that some music excerpts can prime semantically related words, and trigger brain responses (N440 signatures) typical of semantic relatedness. From the present perspective, priming effects of this kind are compatible with the view that music conveys semantic information, but one does *not* expect that it does so by the same mechanisms as language. If anything, musical excerpts should stand to words as abstract visual animations stand to words. More fine-grained results on the typology of priming effects could be informative in this connection.

(vi) Last, but not least, these preliminary investigations have been quite parochial, since they were restricted to a few pieces of Western classical music. A cross-cultural investigation of music semantics should prove illuminating. From the present perspective, we might expect that inferences drawn from normal auditory cognition are less subject to variation than tonal inferences because the

latter are drawn on the basis of formal properties of tonal pitch space that are subject to variation (see Stevens 2012 for a review of cross-cultural musical research).

Sound examples

The sound examples can be downloaded at the following URL:

https://drive.google.com/file/d/0B7Mz-VKVeYNKTE9YYnZFSjJlem8/view?usp=sharing

Credits for sound examples

S05 Hungarian National Philharmonic Orchestra - Amazon.com Song ID: 235987040

S05.1 Hungarian National Philharmonic Orchestra Amazon.com Song ID: 235987038

S07.2 Kurt Masur: Leipzig Gewandhaus Orchestra

S29 Daniel Barenboim, Mozart: Complete Piano Sonatas and Variations, Piano Sonata No. 1 in C, K.279: I. Allegro

S31 Haydn: Symphony #104 In D, H 1/104, "London" - 1. Adagio, Allegro
Adam Fischer: Austro-Hungarian Haydn Orchestra (startin at 2'29).

S32 Margarete Babinsky Piano Sonata in A, K.331: I. Andante Grazioso. Mozart Piano Sonatas

S36 Simon Boccanegra Teatro La Fenice 2015-2015, conductor Myung-Whun Chung, RAI, with Simone Piazzola as Simon

S37 Simon Boccanegra Teatro La Fenice 2014-2015, conductor Myung-Whun Chung, RAI, with Simone Piazzola as Simon

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The present manuscript presents the 'bare bones' of an account sketched in greater detail in Schlenker 2016.

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